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BIMONTHLY BIRD COUNTS AT SELECTED OBSERVATION POINTS AROUND SAN FRANCISCO BAY, FEBRUARY 1964 TO JANUARY 1966[1]

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A 2-year study was conducted in 1964 and 1965 to identify and count the birds using the San Francisco Bay estuary. The bird population was observed twice monthly at 13 census areas around the Bay estuary. From 1 to 26 observation points were selected within the different census areas to provide good access without visual overlap.

Five habitat types were delineated as open water, tidal flats, marsh, saltpond, and other (inflight). The birds were separated into 11 types, namely pelicans, shorebirds, loons, cormorants, herons, ducks, geese, grebes, rails and coots, gulls, and terns.

In 1964 3.5 million birds were counted and in 1965 3.8 million. Most of the birds identified were shorebirds (55%), while waterfowl were the second largest number of birds observed (34%). Bird numbers were lowest during the summer months when only resident and small migratory bird populations were present, and they reached a peak in the fall and winter when large numbers of migrants arrived. The migratory species were the majority of birds that used the Bay from late fall to early spring.

Waterfowl migrating into the Bay area in December 1964, exceeded 500,000 and, in December 1965, were approximately 200,000. The mudflat and saltpond habitats had the highest bird densities during the study. Bird density records for the marsh areas were very low, possibly due to the dense vegetation obstructing observers' vision and the secretive nature of marsh birdlife.

The magnitude of the bird numbers recorded for the five habitat types points to the San Francisco Bay estuary as a vital system for the continuance of the present level of birdlife.

INTRODUCTION

The San Francisco Bay is a vast ecosystem which contains numerous species of wildlife. Fish, birds and aquatic animals are found in abundance on various areas around and within the Bay.

This study, while concerned only with recording the bird counts for the Bay and its shoreline habitats, was the first basically important step in assessing the role which this area plays in support of wildlife.

It was the first large-scale study of the magnitude of bird populations in a well-defined but relatively large area contiguous to a megalopolis

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where urbanization and industrialization have greatly encroached and continues to encroach on fish and wildlife habitat.

In the past, the value of land and water for fish and wildlife production and support could not be assessed; even partial or indirect indicators, such as those presented in this report, were lacking. Intense competition for the use of habitat, especially that bordering San Francisco Bay, also applies to many other marine estuaries in California. The resources involved have alternative uses. The preservation of land and water for wildlife use can incur high costs since the industrial and home real estate, water supply and mineral production benefits in some instances are considerable. Nevertheless, the demand for bird watching, fishing and hunting, whose benefits are difficult to measure, is growing rapidly. This does not imply that these benefits are not substantial. While, in this study, the use by the populace of the bird resources of the area was not measured, i.e., the number of days of bird watching, this might well be the next phase of the investigation.

Where unique resources are involved, an analyst has to cope with defining economic and technological irreversibility. What is the optimum amount of the Bay's various habitats that should be maintained? Probably society can afford the first yard with much less loss in marine life than that involved in taking a subsequent segment; but to determine the point at which values foregone are greater than those gained is extremely difficult, demanding a good knowledge of the total ecosystem and its overall production possibilities. Where the line of demarcation is to be drawn is difficult to gauge, but various kinds of analysis for San Francisco Bay can give us useful insights.

With the future envisaged population of the Bay area and the accessibility to birdlife, supported by the Bay habitats, these unique recreational experiences will increase in worth. Some assessment of these future benefits should enter decisions as to future use of the Bay area.

The argument that society forfeits very little in terms of some of the market products the Bay habitat produces, if the habitat were to be maintained for fish, bird, and other wildlife support and production, should be critically examined. The possibility that there are more accessible and better places for obtaining some of these raw materials should be appraised.

STUDY AREA

The study area included specific parts of the San Pablo and San Francisco bays. Thirteen census areas were established within these two bays (Figure and Table 1). The census areas were further divided into 139 ground observation points. The observation points were strategically positioned to avoid any overlap with adjacent observation points.

METHOD AND APPROACH

Approximately 60 trained and knowledgeable volunteer observers, most of whom were members of the Audubon Society, made the bird counts. The bird counting periods were scheduled on or about the 1st and 15th of each month beginning on February 15, 1964. Because of adverse weather, changes in access, and too few census personnel, observations did not occur on all days scheduled. Although the census period did not constitute exactly 2 years, the data obtained on the days of

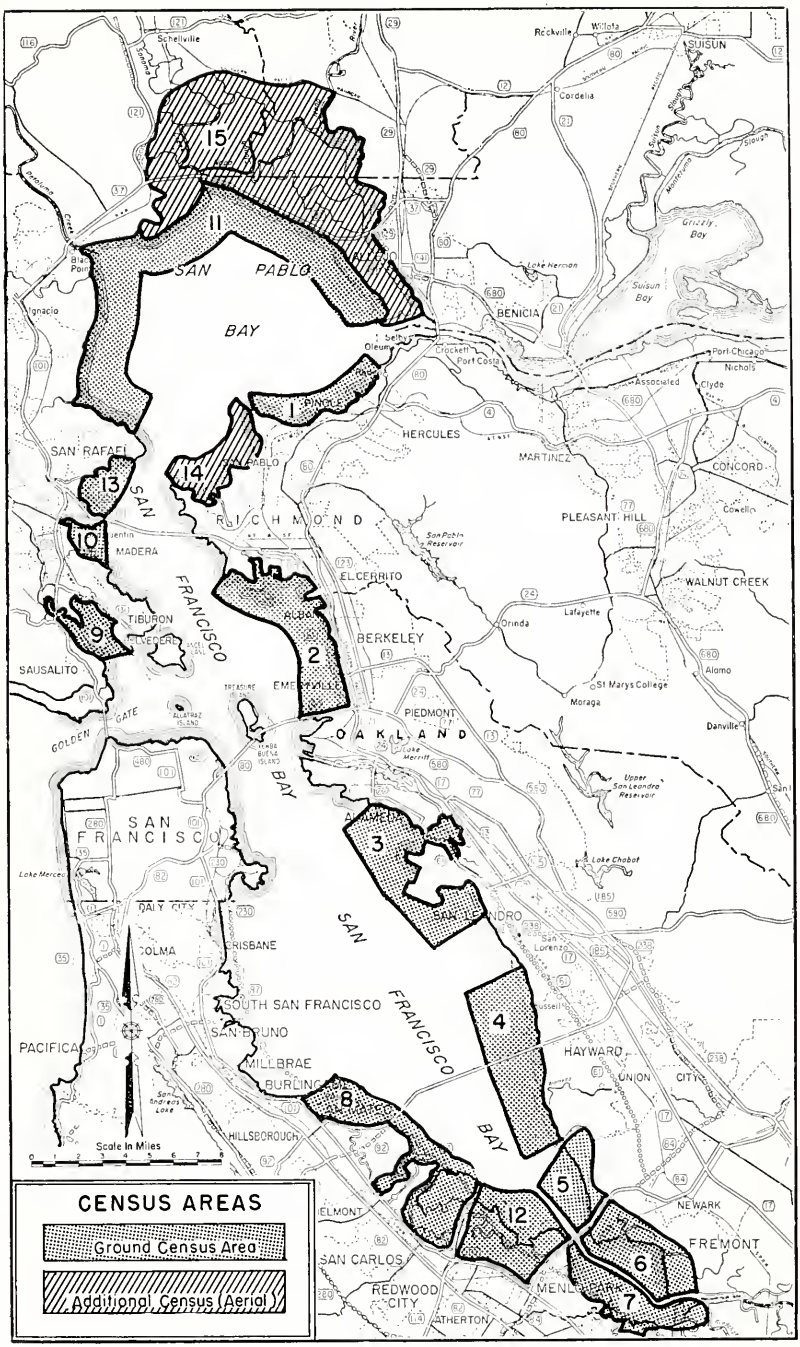

FIGURE 1 Map of San Francisco Bay bird census areas.

TABLE 1

The Census Areas and Number of Observation Points Within Each Area

Census area number	Location	Number of observation points within census area
1	Pinole—Lone Tree Point to Pinole Point	6
2	Berkeley—Richmond Point to Oakland Bay Bridge	7
3	Alameda—Alameda to San Leandro	24
4	Hayward—San Lorenzo Creek to Coyote Hill Slough	19
5	Coyote Hill—Coyote Hill Slough to Dumbarton Bridge	4
6	Newark—Dumbarton Bridge to Coyote Creek	9
7	Palo Alto—Moffett Air Station to Dumbarton Bridge	16
8	San Mateo—Redwood Point to Coyote Point	20
9	Richardson Bay	1
10	Corte Madera Bay	1
11	San Pablo Bay—China Camp to Marc Island	5
12	Menlo Park—Dumbarton Bridge to Redwood Point	26
13	San Rafael Bay	1
	Total	139

observations are considered representative of two annual cycles. The counts were scheduled on ebbing tidal stages in order to obtain maximum bird numbers along the shoreline.

Later in the survey period, an aerial survey was also conducted for estimating bird numbers. It was carried out along the same guidelines as those used by the ground survey crews. The counts made by the aerial crew took in two additional areas (Figure 1). The aerial counts in January 1965 and 1966 were directed primarily toward a waterfowl census within the Bay system.

The habitat was separated into five basic types: (i) open water, (ii) tidal flats, (iii) marsh, (iv) saltponds, and (v) other. The "other" category refers to the observation and recording of flying birds and is not properly a habitat type. The habitat within each of the 13 census areas varied as did the number of acres of each habitat (Table 2). Saltponds did not exist at eight of these areas while marshland was 250 acres or less at five of the census areas.

The composition of the habitat within a census area doubtless influenced the number and type of birds supported. The bird species were categorized as 11 bird types, namely, pelicans, shorebirds, loons, cormorants, herons, ducks, geese, grebes, rails and coots, gulls, and terns. A more abbreviated delineation of bird groups was made for the purpose of distribution, and these were shorebirds, waterfowl, and others.

Bird counts were tabulated and grouped. The grouped counts were transposed to IBM punch cards for statistical purposes and to reduce data volume.

Two definitions were used to indicate the number of birds at observation points, that is *sightings* and *observations*. A *sighting* was recorded when one of the 11 bird types was seen on a particular habitat. For example, if pelicans were sighted on tidal flats, saltpond and open water habitats then three pelican bird-type sightings were recorded.

TABLE 2

Habitat Acreage for Each Census Area

Census area	Open water	Tidal flats	Marsh	Saltpond	Other	Total
1	4,000	760	250	0	0	5,010
2	6,240	660	200	0	0	7,100
3	10,000	2,100	690	0	0	12,790
4	22,000	3,960	1,500	1,500	0	31,460
5	1,700	1,800	180	2,650	0	6,330
6	300	11,940	14,400	2,640	0	29,280
7	1,800	3,700	1,200	1,800	0	8,500
8	3,700	3,100	2,000	0	0	8,800
9	3,300	550	180	0	0	4,030
10	315	970	330	0	0	1,615
11	12,000	11,500	3,650	0	0	27,150
12	1,700	2,900	1,400	3,260	0	9,260
13	900	750	260	0	0	1,910
Total	67,955	44,690	26,240	14,350	0	153,235

Another example would be if shorebirds were seen on four habitat types then a total of 4 shorebird sightings were recorded. Sightings, therefore, were correlations between bird types and habitat.

An *observation* was recorded when a particular bird was present at an observation point, irrespective of the habitat type. An example would be if pelicans, shorebirds, gulls, terns and ducks were seen at a particular observation point then a total of five bird type observations were made for that particular recording period. Observations, therefore, were correlations between bird types and the observation point.

The observation points within each census area were ranked for each year, 1964 and 1965, by:

1. Total bird count for the year, that is, the summation of the number of birds counted for each observation day in the year.
2. The average number of birds per observation day during the year.
3. The average number of birds per sighting during the year.
4. The maximum number of birds observed on any one observation day during the year.
5. The minimum number of birds observed on any one observation day during the year.

These ranking characteristics were repeated for the census area at a particular observation date. The density of bird populations on any one observation day at a census area may be ascertained from the ranking for this characteristic.

RESULTS

The lowest bird use of the Bay habitat occurred during the summer months (Figures 2 and 3). The migratory bird population increased rapidly during the early part of September and reached a peak in December (Figures 4 and 5). The influx of migrating waterfowl pro-

vided the largest percentage of birds in the Bay during December (Figures 4 and 5).

In 1965 the total bird numbers were greater than in 1964 with a higher count in the early months of 1965 than the same months of 1964. The shorebird migration preceded the waterfowl migration by about 2 months in both 1964 and 1965. The recorded waterfowl numbers were the highest in December for both years (Figures 4 and 5).

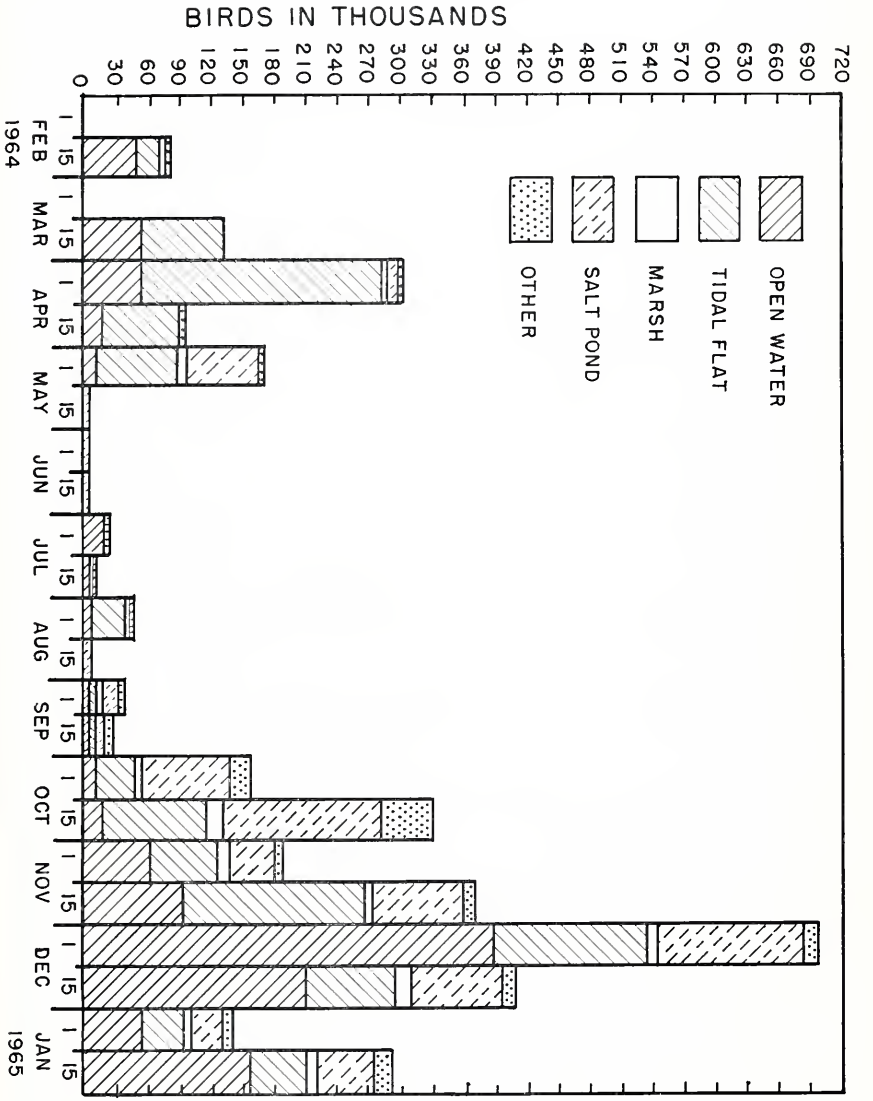

FIGURE 2 Distribution of birds by habitat and by census period February 1964 to January 1965.

The resident birds, shown as "other birds" in the graphs, constituted only a small percentage of the total birds counted in any one year. This does not imply that the environs of San Francisco Bay are not an important habitat for these species. It does, however, point to the importance of San Francisco Bay as a resting and feeding area for waterfowl in the Pacific Flyway.

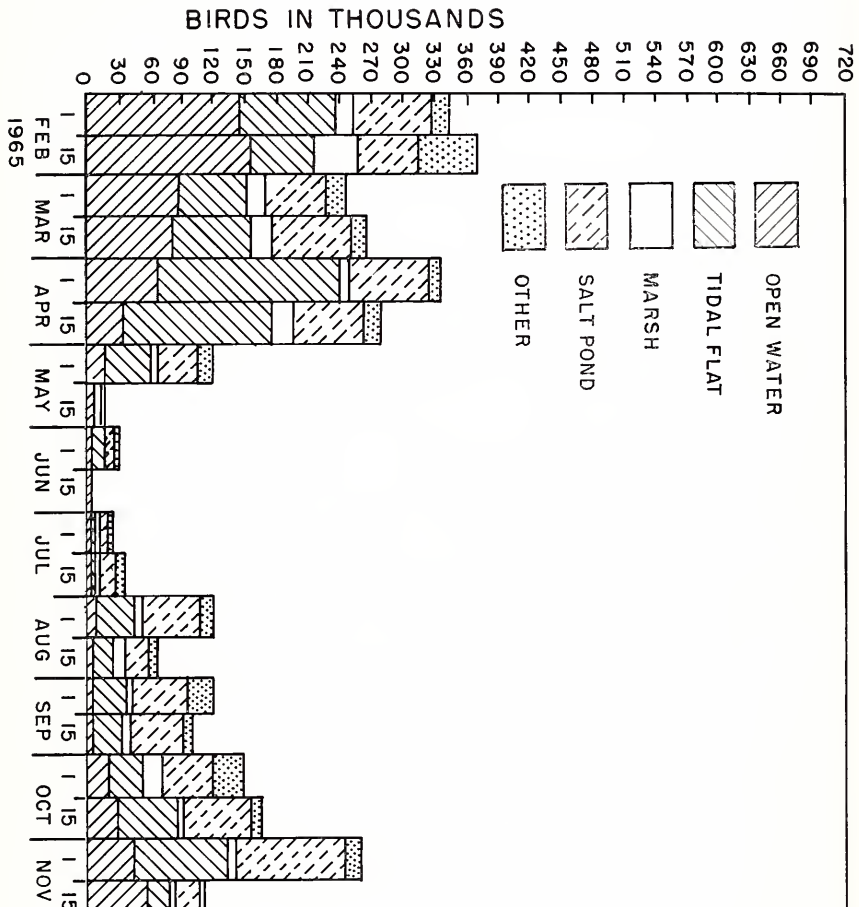

FIGURE 3 Distribution of birds by habitat and by census period February 1965 to January 1966.

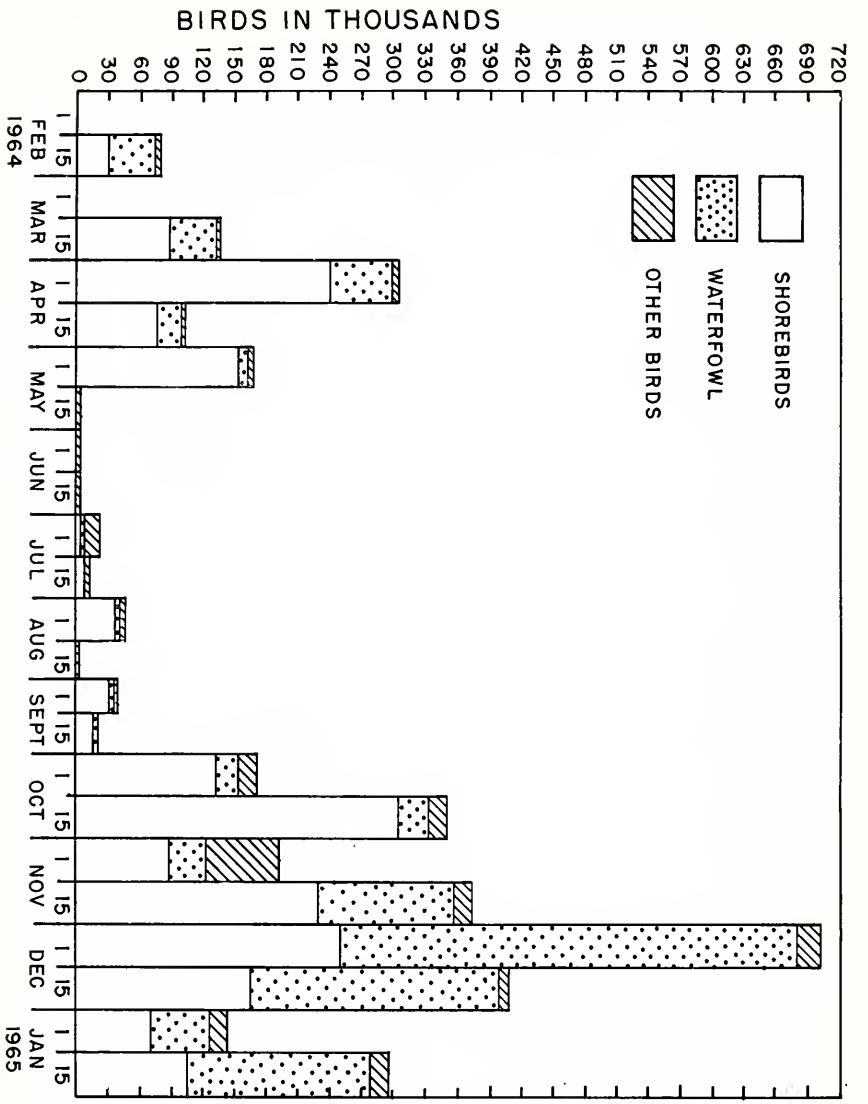

FIGURE 4 Numbers of birds by species group and census period February 1964 to January 1965.

Some 3.5 million birds were counted in 1964 and approximately 4 million in 1965 (Table 3). Shorebirds and ducks, approximately 2 million in 1964 and $1\frac{1}{4}$ million in 1965, constituted the most numerous of the 11 types, while geese and loons were present in very small numbers, 200–400 and 40–70, respectively. The magnitude of the bird population gives some overall estimate of the importance of the Bay to bird support.

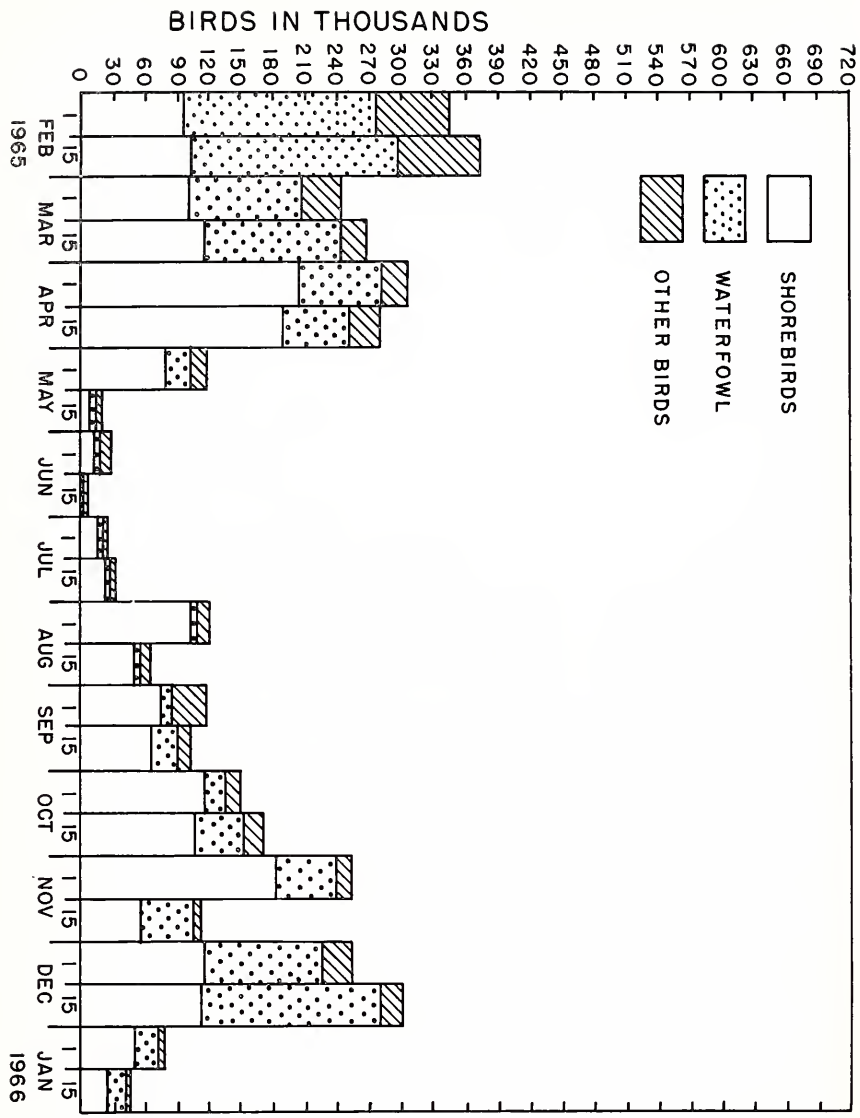

FIGURE 5 Numbers of birds by species group and by census period February 1965 to January 1966.

In December 1964, 525,000 waterfowl were sighted at the land areas under observation. In December 1965, approximately 200,000 waterfowl were counted.

Ducks and shorebirds provided the largest average of all birds counted in 1964 and 1965 (Table 4).

Ducks and shorebirds, again provided the greatest number of sightings during 1964 and 1965. There were 1,509 shorebird sightings made

TABLE 3

Total Number of Birds Counted for All Land Areas
1964–1965

Bird type	Open water		Tidal flats		Marsh		Saltpond		Other		Total	
	1964	1965	1964	1965	1964	1965	1964	1965	1964	1965	1964	1965
Pelican	1,010	765	60	575	170	95	7,720	9,755	2,340	2,710	11,300	13,900
Shore birds	52,250	61,450	1,199,900	1,157,700	67,950	125,700	629,200	562,950	104,400	90,750	2,053,700	1,998,550
Loons	34	65	2	0	0	2	0	0	0	2	36	69
Cormorant	1,210	3,050	55	155	640	395	1,360	4,150	3,865	4,550	7,130	12,300
Heron	218	590	2,149	1,944	1,280	2,852	1,065	2,995	718	811	5,430	9,192
Ducks	1,057,500	866,500	33,750	23,600	17,750	19,200	135,300	328,800	32,850	33,950	1,277,150	1,272,050
Geese	0	120	0	170	0	20	0	10	220	75	220	395
Grebes	8,160	13,720	115	70	210	140	3,365	20,550	130	410	11,980	34,890
Coots	9,305	9,160	3,475	4,050	2,560	14,170	13,215	12,275	6,875	8,540	35,430	48,195
Gulls	60,650	69,100	48,000	70,100	500	14,450	29,100	99,950	22,150	153,050	160,400	406,650
Terns	2,325	3,355	2,000	3,424	700	800	4,125	8,750	1,340	4,365	10,490	20,695
Total	1,192,662	1,027,875	1,289,506	1,265,788	91,760	177,824	824,450	1,050,185	174,888	299,213	3,573,266	3,816,886

TABLE 4

Average Number of Birds Counted Per Sighting for All Land Areas
1964–1965

Bird type	Open water		Tidal flats		Marsh		Saltpond		Other		Total	
	1964	1965	1964	1965	1964	1965	1964	1965	1964	1965	1964	1965
Pelican	40	16	10	11	57	32	198	177	90	82	114	74
Shore birds	568	445	1,843	1,135	306	297	1,942	921	475	240	1,361	778
Loons	2	3	2	0	0	2	0	0	0	2	2	3
Cormorant	36	29	18	39	128	99	91	75	99	57	74	50
Heron	5	10	13	7	10	8	12	19	7	5	10	9
Ducks	2,471	1,174	392	189	206	102	825	832	291	179	1,456	777
Geese	0	17	0	57	0	10	0	10	28	15	28	22
Grebes	57	40	13	10	13	10	60	99	10	13	50	58
Coots	92	58	70	59	59	89	197	131	237	208	119	93
Gulls	778	171	1,000	246	50	201	351	282	363	393	573	270
Terns	17	16	29	31	17	17	42	38	21	16	26	24
Total	1,087	462	1,186	649	163	141	885	485	259	188	820	416

during 1964 and 2 570 sightings in 1965 (Table 5). The total number of sightings for 1965 was about 53% larger than the 1964 totals. Although the total number of sightings increased in 1965, the average number of birds per sighting decreased from 820 in 1964 to 416 birds per sighting in 1965 (Table 5).

TABLE 5

The Number of Bird Sightings and the Average Number of Birds Sighted 1964–1965

Bird type	1964		1965	
	Number of sightings	Average number of birds per sighting	Number of sightings	Average number of birds per sighting
Pelicans	99	114	189	74
Shorebirds	1,509	1,361	2,570	778
Loons	15	2	26	3
Cormorants	96	74	247	50
Herons	528	10	1,007	9
Ducks	877	1,456	1,687	777
Geese	8	28	18	22
Grebes	238	50	600	58
Rails and Coots	297	119	521	93
Gulls	280	573	1,504	270
Terns	408	26	866	24
All birds	4,355	820	9,235	416

When viewed over a 2-year period, a pattern emerged. Shorebirds, ducks, and gulls were sighted most frequently and in greater numbers. Herons, terns, and grebes, while sighted quite often, were present in much smaller numbers. Pelicans, cormorants, loons, and geese were sighted less frequently and in comparatively small numbers. However, a 2-year period is not sufficient time in which to record fluctuations in populations. Doubtless, bird populations in the Bay area are subject to irregular and cyclical changes.

Another useful measure of the bird populations that are present during any given year is the average number of birds seen per sighting. Table 6 presents a comparison of the average bird counts per sighting for 1964 and 1965 and the yearly ranking of each land area on this basis. Generally, the most intense support areas, as far as average bird counts per sighting, did not change drastically during the 2-year survey. Land areas 9, 10, and 11 did not have all the habitat types present. All three of these areas were lacking the saltpond habitat type. That the land areas changed positions in terms of bird support from one year to the next only confirmed the need for a comprehensive study over a period of years to adequately identify, even if only by gross measures, the support capability of habitat. The ranking of sites for bird support does provide an insight on the geographic areas that are heavily utilized.

TABLE 6

Average Bird Count Per Sighting at Each Census Land Area and Their Yearly Ranking—1964 and 1965

1964			1965		
Ranking	Census land area	Average bird count per sighting	Ranking	Census land area	Average bird count per sighting
1	11	2,263	1	9	1,364
2	10	2,055	2	11	968
3	9	1,433	3	4	580
4	4	1,238	4	5	519
5	13	1,077	5	10	504
6	2	797	6	6	499
7	6	768	7	2	480
8	7	745	8	7	431
9	8	661	9	13	314
10	5	618	10	3	303
11	3	591	11	8	287
12	12	470	12	12	261
13	1	159	13	1	170

The sightings of the various bird types at the sites that were surveyed indicated some measure of specificity with respect to the habitat. Loons, cormorants, and geese were not seen on several of the land areas. For instance, over the 2-year survey period, loons and geese were not sighted on land areas 1, 5, 6, 10, and 13 (Table 7). Each land census area had a bird support habitat that was somewhat different from the others. They attracted and supported different bird species and at various population levels. It was not uncommon to find some bird species totally lacking on specific areas and at specific times. Wildlife seeks the habitat on which it is dependent.

The results of the aerial survey differed from the ground census results. On all observation periods (except September and January 1965) the ground counts exceeded the aerial counts.

Bird densities per acre for shorebirds were the highest during the winter and early spring months, while waterfowl densities were highest in winter months only (Table 8).

An average of 24 birds per acre were found on the four habitats during the study. The saltponds and tidal flats had the highest average densities (Table 9). These areas were somewhat free of obstructions that would interfere with observation so that bird counting was much easier and more accurate. The marsh habitat type, because of its vegetative cover had the least number of bird sightings. This does not mean that the Bay marshes are of less importance in the overall ecosystem. Wildlife using marshlands is secretive and observed only infrequently.

DISCUSSION

The bird counts obtained can be regarded as fairly reliable estimates of bird populations found in and around the Bay on the specific observation days. Obviously, the counts do not imply the inherent im-

TABLE 7

Average Sightings by Bird Type at Land Census Areas
1964–1965

Bird types	Land census areas																									
	1		2		3		4		5		6		7		8		9		10		11		12		13	
	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65	'64	'65
Pelicans	0	0	12	20	34	10	311	124	253	35	10	155	129	179	79	18	43	23	0	10	10	10	77	19	0	10
Shorebirds	294	315	1,127	974	1,028	571	2,508	943	883	937	401	923	1,251	1,023	1,022	523	2,440	975	5,515	1,944	5,658	3,332	844	506	1,055	433
Loons	0	0	2	4	2	2	0	2	0	0	0	0	2	2	2	2	5	8	0	0	0	0	2	2	0	0
Cormorant	10	0	10	10	10	10	38	15	55	0	0	0	54	74	61	40	136	26	10	10	0	21	203	59	0	10
Heron	11	7	2	3	5	6	7	12	9	9	5	6	12	18	12	3	13	13	32	17	13	8	6	5	47	20
Ducks	278	372	2,958	575	1,116	598	1,711	1,291	1,202	480	2,600	734	1,847	770	758	510	3,539	4,000	2,831	743	2,038	1,110	507	521	1,955	939
Geese	0	0	0	10	0	10	10	10	0	0	0	0	0	10	0	23	0	10	0	0	10	51	57	35	0	0
Grebes	10	10	23	14	39	14	82	102	36	151	10	23	12	13	13	12	559	697	23	19	37	11	38	64	10	32
Coots and rails	10	10	39	20	51	72	211	110	10	0	0	16	160	175	10	10	188	106	55	55	48	93	112	37	0	146
Gulls	50	66	427	497	308	231	770	281	405	395	6,070	188	493	275	0	191	503	2,438	400	158	338	245	278	212	0	65
Terns	19	27	35	42	15	17	47	36	46	34	31	20	26	35	20	16	53	16	27	23	42	24	16	14	10	18
Total avg.	159	170	797	480	591	303	1,239	580	618	519	768	499	745	431	661	287	1,433	1,364	2,055	504	2,263	968	470	261	1,077	314

TABLE 8

Bird Densities Per Acre for All Land Areas—Ground Counts Compared With Aerial Counts From September 1, 1964, to January 1, 1966

Date	Bird type							
	Shorebird		Waterfowl		Other		Total	
Sept 1, 1964	0.25	(0.15)	0.01	(0.03)	0.02	(0.00)	0.28	(0.18)
Oct 1	0.85	(0.25)	0.14	(0.12)	0.06	(0.01)	1.05	(0.38)
Nov 1	0.56	(0.14)	0.24	(0.21)	0.46	(0.04)	1.26	(0.39)
Dec 1	1.72	(0.34)	2.90	(0.33)	0.16	(0.00)	4.78	(0.67)
Jan 1, 1965	0.45	(0.18)	0.38	(0.32)	0.11	(0.04)	0.94	(0.54)
Feb 1	0.63	(0.65)	1.20	(0.27)	0.46	(0.02)	2.29	(0.94)
Mar 1	0.65	(0.21)	0.70	(0.11)	0.26	(0.02)	1.61	(0.34)
Apr 1	1.38	(0.55)	0.51	(0.20)	0.13	(0.01)	2.02	(0.76)
May 1	0.52	(0.21)	0.15	(0.16)	0.12	(0.01)	0.79	(0.38)
June 1	0.10	(0.02)	0.03	(0.06)	0.06	(0.01)	0.09	(0.05)
July 1	0.10	(0.04)	0.01	(0.01)	0.06	(0.00)	0.17	(0.05)
Aug 1	0.72	(0.49)	0.01	(0.00)	0.09	(0.01)	0.82	(0.50)
Sept 1	0.47	(0.68)	0.06	(0.08)	0.23	(0.02)	0.76	(0.78)
Oct 1	0.72	(0.52)	0.12	(0.14)	0.12	(0.01)	0.96	(0.67)
Nov 1	1.20	(0.38)	0.36	(0.30)	0.14	(0.01)	1.70	(0.69)
Dec 1	0.74	(0.44)	0.77	(0.55)	0.18	(0.05)	1.69	(1.04)
Jan 1, 1966	0.31	(0.41)	0.14	(0.36)	0.04	(0.01)	0.49	(0.78)

( ) Aerial Counts.

TABLE 9

Average Bird Densities for All Bird Types Per Acre

Year	Open water	Tidal flats	Marsh	Saltpond	Total
1964	17.78	29.88	3.50	57.25	23.64
1965	15.20	29.01	6.78	72.93	25.25

portance of any one site in the overall process of sustaining bird populations in the Bay area. The relationships between one site and another site or between the different types of habitat, that is open water, tidal flats, marsh, and saltpond within a specific census area are imprecisely understood. The role played by each site in the biological systems supporting birdlife would entail comprehensive biological investigations. Likewise, the effect on the productivity of bird supporting sites, as a result of improvement in water quality, cannot be gauged, nor can its effect be judged in terms of the composition of the bird populations.

These important relationships cannot be analyzed from this study, which is essentially a bird inventory in the Bay area. However, the survey does yield valuable information on the various bird populations and their relative numbers, the importance of the Bay sites to migrating waterfowl, and an approximate ranking of habitat quality that supports birdlife in the Bay area.

The ground count seemed more reliable than the aerial count. However, ground counts required many observers scattered over a wide area. The aerial counts used only two observers. If aerial surveying were to be used as the least-cost census method, then some improvement will be needed for this system. It is possible that a more controlled experiment would reveal certain types of birds that are not readily seen from the air. There also may be omissions of birds sighted in the ground survey which would also affect the final results.

The specific bird data for each census area and observation point is on file in the California Department of Fish and Game's Region 3 Office, Room 3000, Ferry Building, San Francisco, California.

SUMMARY

The primary objective of this study was to observe and count the number of various bird species using San Francisco Bay.

The number of birds sighted exceeded 3.5 million annually. Of the 11 classifications of birds, shorebirds and ducks predominated.

The Bay environs is an important feeding and resting area for migratory birds, as evidenced by the large number of these species sighted in the months of November, December, and January. Waterfowl sightings in the month of December exceeded 500,000 in 1964 and approximately 200,000 in December of 1965.

Bird densities were highest on tidal flats and saltponds. There were indications that the marsh areas had a very low bird density which is not necessarily accurate. Dense vegetation in marsh areas restricted observation while saltponds and tidal flats had little vegetation. Each habitat provides the conditions necessary for birdlife and, therefore, cannot be assessed independently of the others. In the total environment, the marsh habitat is just as important as the mudflat areas.

A continuation of past and present trends in the removal and destruction of wildlife habitats in San Francisco Bay can but reduce bird populations and may accelerate the extinction of certain species. When demands for improvement of environmental quality are increasing, the present and future value to society of having a thriving bird population so accessible and located in the heart of a megalopolis should not be summarily dismissed as of little consequence. This study, conducted as a result of patient effort by many interested in maintaining the birdlife of the Bay, is but one phase of the overall measurement of the value of this resource.

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A PRELIMINARY STUDY OF THE RELATIONSHIP OF SALTPONDS AND WILDLIFE—SOUTH SAN FRANCISCO BAY[1]

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Five salt evaporation ponds in Alameda County were evaluated as wildlife habitat. Data were collected from September 1967 to September 1969. Salinity ranged from 9 Sal. (percent of saturation) as the minimal in Pond 1 to a maximum of 93 Sal. in Pond 6. Fifty-five bird species were recorded in the ponds. Among the birds making heavy use of salt ponds were shorebirds, ducks, grebes and Bonaparte's gulls (*Larus philadelphia*).

Dabbling ducks, coots and fish-eating birds exhibited a marked preference for Pond 1. Diving ducks, grebes, phalaropes and Bonaparte's gulls disclosed a high degree of salinity tolerance and a predilection for food items existing in ponds of high salinity. Shorebirds, except phalaropes, made heaviest use of ponds almost regardless of salinity and which were sufficiently shallow for wading.

INTRODUCTION

Four major wildlife habitat types exist in and around South San Francisco Bay, namely salt marsh, salt production lands, tidal flats and open water.

The area south-east of Redwood Creek, San Mateo County, and south of Coyote Slough, Alameda County includes approximately 24,000 acres of salt ponds and 3,500 acres of marsh. The salt production lands are reclaimed salt marshes, tidal flats and sloughs.

In the process of salt production, sea water passes first through a series of outer or concentration ponds where it is evaporated to saturation with respect to sodium chloride, and the less soluble salts are precipitated. The final concentrating pond of saturated brine is called the "pickle" or "lime" pond. At this point evaporation has reduced the volume of pickle to about 10% of its original quantity. Next, the pickle is transferred into a separate group of ponds called crystallizing ponds where continued evaporation precipitates the salts (Ver Planck 1958).

During the early stages of evaporation the ponds sustain a variety of organisms that vary in abundance in relation to salinity and temperature. Some of these organisms are often present in enormous quantities and serve as food items for many species of birds.

The objectives of the study were to evaluate salt evaporation ponds as wildlife habitat, and to identify the reasons for significant variation in wildlife use of these ponds.

[1] Accepted for publication June 1970. This study was supported in part by Federal Aid in Wildlife Restoration Project W-52-R "Wildlife Investigations Laboratory."
[2] Now retired from State service.

LOCALE OF THE STUDY

Five salt evaporation ponds situated between Mowry Slough and Coyote Creek, in Alameda County, were selected because of (i) fair accessibility and (ii) known differentiation in wildlife use (Figure 1). The pond sizes were as follows: Ponds 1, 520 acres; 3, 590 acres; 4, 480 acres; 5, 430 acres; and 6, 430 acres; for a total of 2,450 acres.

Salt water is pumped from Mowry Slough into Pond 1, and from there it passes through ponds 2, 3 and 4. From 4, the water is siphoned under the Southern Pacific Railroad right of way and passes through ponds A22 and A23, then goes through another siphon and enters ponds 5 and 6 (Figure 1).

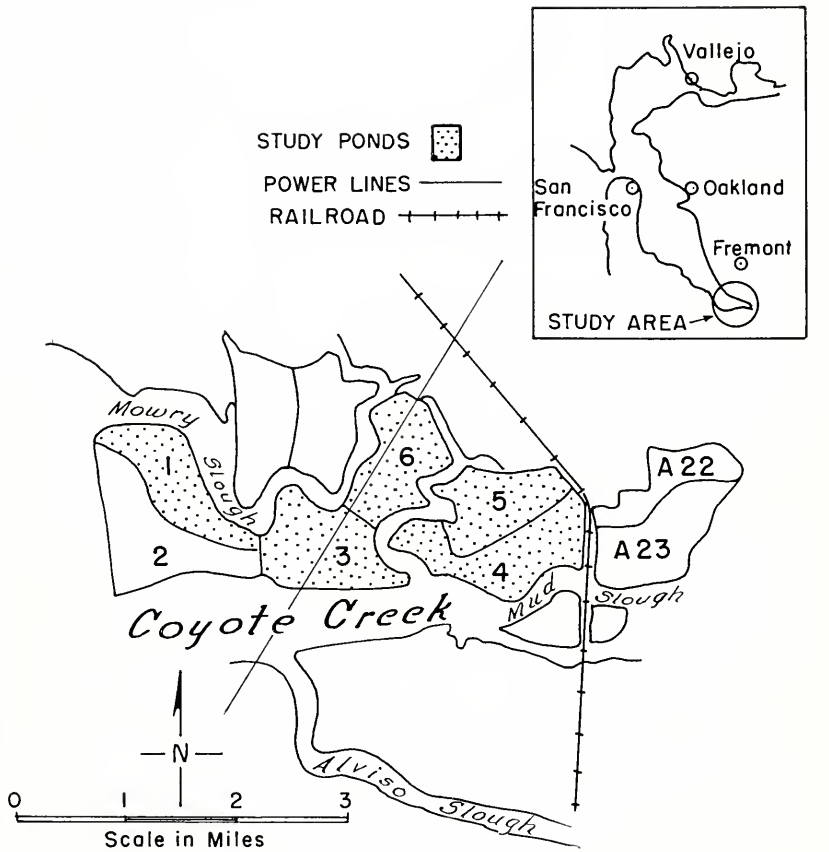

FIGURE 1 Map of salt ponds study area. Drawn by Cliffa Carson.

METHODS

Organisms contained in the water as well as those living on or in the bottom of the ponds were sampled and later identified and enumerated by the Wildlife Investigations Laboratory. This phase of the study was done in September 1967 and February 1968.

Thirty-eight bird specimens were collected in September 1967 and 51 during February 1968 for a total of 89 specimens (Table 1).

The salinity, depths and temperature of water were extracted from the records of Leslie Salt Company after conclusion of the field work.

The number and species of birds occupying each pond were estimated twice monthly, when possible. To obtain data for all months of the year, it was necessary to extend the study from September 1967 to September 1969.

TABLE 1

Specimens Collected

Species	Sept. 1967	Feb. 1968	Total
Shoveler	4	5	9
Lesser Scaup	0	5	5
Widgeon	0	2	2
Ruddy Duck	3	7	10
Green winged teal	0	1	1
Cinnamon teal	1	0	1
Pintail	4	0	4
Redhead	0	2	2
Eared grebe	0	5	5
Dunlin	0	9	9
Western sandpiper	6	1	7
Least sandpiper	5	4	9
Avocet	5	7	12
Willet	0	3	3
Northern phalarope	5	0	5
Wilson's phalarope	5	0	5
Total	38	51	89

RESULTS

Results of Organism Sampling

The organisms common to abundant in bottom and water samples were scuds or fairy shrimp (*Callianassa* sp.), brine shrimp (*Artemia salina*), copepods, water-boatman beetles (*Trichocorixa reticulata*), brine flies (*Ephydra cinerea*), snails, round worms, seed shrimp, polychaete worms, and rotifers.

The dog whelk snail (*Nassarius obsoletus*), although exceedingly abundant on tidal flats, normally does not survive long in salt ponds. This and other snails possibly were represented by shell fragments remaining in some of the ponds.

Brine shrimp were not found in ponds 1 and 2, however, they were abundant in ponds 5 and 6.

The only vascular plant species found growing as a submerged aquatic was widgeon grass (*Ruppia maritima*). It occurred in sparse colonies in Pond 1.

It cannot be assumed that the bottom and water samplings resulted in a complete inventory of organisms. Carpelan (1957) listed many animal species ranging from zooplankton to fishes in six salt ponds near Alviso.

Results of Food Habits Study

Some birds collected had empty digestive tracts and others contained only waste materials incidentally ingested. Some of the food items obviously were not obtained in the salt ponds.

Ducks

Widgeon grass seeds accounted for 85.7% of the stomach contents in seven ruddy ducks, 66.2% in three pintail, and 65% in one cinnamon teal.

Water-boatman beetles amounted to 68.3% of the stomach contents in three ruddy ducks collected in September 1967 and 14.3% in the ruddy ducks collected in February 1968.

Brine fly larvae and puparia made up 20% of the stomach contents of five lesser scaup (*Aythya affinis*) (Appendix I).

Grebes

Five eared grebes were collected from Pond 6 in February 1968. Feathers were 62.0% of the stomach contents and unidentified matter 27.0%. The only known food items consumed by these birds were brine shrimp (8.6%) and small quantities of brine flies and beetles. The curious habit of consuming large quantities of feathers, common to all species of grebes, is not fully understood (Appendix II).

Shorebirds

Brine flies (larvae and puparia) were taken in significant quantities by all species of shorebirds collected. Water-boatman beetles were the key food item of phalaropes and were also taken by least sandpipers and avocets. Polychaete worms appeared to be an important food item of willets (Appendix III).

Results of Salinity, Depth and Water Temperature

San Francisco Bay is influenced by the Sacramento and San Joaquin rivers, and its salinity is slightly less than that of the open ocean. The water in South San Francisco Bay normally contains 2.0 g/liter magnesium oxide. During the time of year when the Sacramento River is at flood stage this salt may drop to 0.8 g/liter. Fortunately for the salt industry the influx of fresh water is at its lowest during the evaporating season. Salinity in the Leslie salt plants is generally measured in degrees salometer (Sal.) or percent of saturation (Ver Planck 1958). The data on high, low and average water depth, temperature and salinity were recorded (Table 2). There was an increase in salinity from ponds 1 through 6. The data collected demonstrated an inverse correlation between water depth and salinity.

The average salinity in South San Francisco Bay is 9 Sal. although the measurements fluctuated between 4 and 12 Sal.

Water temperatures had extreme fluctuations. The most severe drop in water temperature occurred between November 15 and December 15, 1967, from 68 F to 36 F. By January 15, the temperature of the water in the ponds had risen to 54 F in some ponds, 56 F in others. There is no evidence to show that a drastic temperature drop of such short duration had any noticeable effect on existing bird populations. Sufficient

food organisms appeared to be available at all times. The highest water temperature was recorded in Pond 6 on September 1, 1968, 88 F.

Since many shorebirds move out to feed on the tidal flats at low tide and feed and rest in the salt ponds mainly at high tide, the tidal stage was recorded. Differences in bird numbers caused by tidal conditions were apparently masked by other factors such as influx or exodus of migrants. Therefore, no correlation could be determined between pond use and tidal stage.

TABLE 2

Salinity, Depth, and Temperature in Salt Ponds

Salinity, percent saturation (Sal.)	Depth in inches	Temperature (F)
	Pond 1	
Avg 11	23	68
Low 9	14	36
High 18	33	82
	Pond 3	
Avg 16	22	64
Low 10	13	36
High 28	33	80
	Pond 4	
Avg 24	22	70
Low 14	14	38
High 42	34	86
	Pond 5	
Avg 60	16	68
Low 41	7	38
High 80	30	84
	Pond 6	
Avg 63	13	69
Low 42	0	38
High 93	28	88

Results of Bird Counts

Fifty-five species of water-oriented birds were recorded on the salt ponds that were studied (Appendix IV). They were divided into 12 groups based on taxonomic relationship and similarity in habitat needs.

Grebes

Of the two species of grebes recorded, pied-billed and eared grebe, only the eared grebe was abundant. The highest number was 6,330 in November 1967. Fifty-four percent were tabulated on Pond 5, and only 1% on Pond 1. It is evident that eared grebes showed a marked preference for ponds with high salinity (Table 3).

Double-crested Cormorant

These birds, at times roosted on the electric transmission towers and the service catwalks which cross Pond 3. During November and December 1967 and 1968 approximately 1,000 cormorants were observed.

TABLE 3

Percent of Birds Utilizing the Salt Ponds

Birds	Pond 1	Pond 3	Pond 4	Pond 5	Pond 6	Total sightings
Grebes	1	8	25	54	12	30,440
Herons	61	19	9	7	4	626
Dabbling ducks	69	13	11	3	4	92,387
Diving ducks	26	36	11	14	13	77,785
Coots	70	19	6	1	4	6,570
Shorebirds	10	8	8	60	14	122,433
Phalaropes	6	23	31	32	8	43,255
Bonaparte Gull	4	12	44	24	16	17,281
Terns	30	2	35	32	1	3,427

These birds evidently feed mainly in the bay since only a few were observed feeding in the salt ponds.

White Pelican

Only Pond 2 was visited by white pelicans. A maximum of 400 pelicans were recorded in October 1967 and 1968.

Herons

Three species of herons were recorded (Appendix IV). These birds were seen mostly in sloughs and marshes. The maximum numbers observed in the salt ponds was 65 in September and 64 in November 1968. Sixty-one percent of all herons were encountered in Pond 1. Their numbers diminished as the salinity of the ponds increased (Table 3).

Geese

Geese appeared in the salt ponds only as accidental visitors, as during periods of high winds. Nine Ross' geese and five snow geese were seen in Pond 5 in January 1969.

Dabbling Ducks

Seven species of dabbling ducks were recorded in the study area (Appendix IV). Sixty-nine percent of the dabbling ducks were counted in Pond 1. In February 1968, 7,150 were present on Pond 1. This group of birds used the ponds from August to May. Ponds 5 and 6 attracted only 3% and 4% respectively, apparently demonstrating unfavorable reaction to high salinity (Table 3).

Diving Ducks

Eight species of diving ducks were observed in the ponds (Appendix IV). They were observed from mid-September to May. Pond 3 had 36% of the diving ducks and Pond 4, 11% (Table 3). The highest count was made on November 1, 1967, when 9,000 diving ducks were estimated on Pond 3. In this group, it appears that salinity, up to a certain point, contributed to favorable food conditions related to pond use.

Coots

Coots arrived in late September and October and departed for the breeding grounds about the end of March. Seventy percent of all coots were found on Pond 1, and 1% on Pond 5 (Table 3). Coots thus displayed a preference similar to dabbling ducks.

Shorebirds Exclusive of Phalaropes

This group was composed of 18 species (Appendix IV). The salt ponds in providing feeding and resting places for the many thousands of shorebirds play an extremely important role. The highest count made during the study was 17,140 on Pond 5 on November 1, 1967. Since most shorebirds are waders rather than swimmers the presence of shallow areas is critical. Sixty percent of these birds were counted in Pond 5 where an uneven bottom enabled them to stand and wade. Pond 6 was similar, however, periods of high salinity between 42 and 93 Sal., approached the tolerance of most food organisms. A shallow portion of Pond 1 had 10% of shorebird use. Ponds 3 and 4 each had 8% of the total, but were too deep for extensive shorebird use (Table 3).

This group of birds used the salt ponds all year. Four species, snowy plover, killdeer, avocet and black-necked stilt bred here, and some nonbreeding individuals of other species were present throughout the summer. The lowest numbers of shorebirds occurred in June. The population peaks occurred around April 15, and November 1.

Phalaropes

Phalaropes (Appendix IV) taxonomically belong in the shorebird category. They are treated in this evaluation as a separate group because of the considerable difference in food habits. Phalaropes are expert swimmers, therefore, little affected by pond depth. Availability of a suitable food supply is the prime attraction.

The Wilson's and northern phalaropes made heavy use of the salt ponds. A third species, the red phalarope occurs irregularly on salt ponds in South San Francisco Bay, but was not encountered during the study.

Phalaropes occurred infrequently from April 15 to May 15, and abundantly from early July to mid-October. The highest number recorded was 10,260 on July 31, 1969. Pond 5 had 32% and Pond 1 6% of the phalaropes (Table 3).

Gulls

Five species of gulls (Appendix IV) were seen regularly on the salt ponds. There is no doubt that organisms existing in the ponds contributed to their diet, however, four species, glaucous-winged, herring, California and ring-billed gulls foraged to a great extent in nearby garbage dumps so that it was considered impractical to include these birds in the present investigation.

The Bonaparte gull was not observed to feed in garbage dumps. From approximately August to May these small attractive gulls were commonly noted on the ponds. In December 1967 3,620 Bonaparte gulls were seen on the study area. Pond 4 received 44% of the use while

Pond 1 had only 4% (Table 3). No specimens were collected for food habits analysis.

Terns

Four species of terns were observed. Least terns and black terns were casual visitors in Pond 1, while Forster's and Caspian terns occurred as regular summer visitors, in fact 100 or more pairs of Caspian terns nested on the dike separating ponds 4 and 5. Forster's terns nested outside the study area as did a small population of least terns. The largest number, 260 terns were tallied in May 1968 and July 1969.

No tern specimens were collected. The principal food item is small fish. The commonest of these appeared to be San Francisco top smelt (*Atherinops affinis affinis*).

Terns were present in the study area from April to October. Their numbers were about equally divided among ponds 1, 4 and 5. The nesting activity mainly was responsible for the numbers in ponds 4 and 5.

RECOMMENDATIONS AND CONCLUSIONS

The study resulted in some clarification of the important role of salt evaporation ponds as wildlife habitat. It also brought to light some areas of weakness in the methods employed, and thus made it possible to point out specific needs for improvements in future studies of this kind. These recommendations are:

1. More effort needs to be devoted to sampling of aquatic and bottom organisms.

2. Field laboratory techniques need to be improved to identify zooplankton and other minute soft organisms which may prove to be important dietary elements of many birds.

3. Fisheries personnel and equipment could assist in adequate sampling and identification of fish species and measurement of their relative abundance.

4. The nature of pond bottoms, chemical and physical properties etc. should be explored and evaluated.

5. More bird specimens should be collected. Some interesting and common species such as Bonaparte's gull were missed in collections of this investigation.

6. One or more tidal marsh areas should be included in any future study as a control for direct comparison. The long, narrow slough situated between Pond 6 and Ponds 4 and 5 is suggested as a suitable control area. This would, incidentally, focus some attention on marsh dwellers such as American bittern (*Botaurus lentiginosus*) and clapper rails (*Rallus longirostris*). Even non-waterbirds, for example short-eared owls (*Asio flammeus*) and white-tailed kites (*Elanus leucurus*), were observed in marshes and possibly should be included in this type of study.

7. Inclusion of a set of salt ponds in another series of salt production lands could prove useful in assessing the validity of assumptions derived from the investigation.

Many species of birds were observed using the salt ponds. Those birds making the heaviest use of the ponds were shorebirds, ducks, grebes and Bonaparte's gulls.

Dabbling ducks, coots and fish eating birds exhibited a marked preference for Pond 1, which had the lowest average salinity. Diving ducks, grebes, phalaropes and Bonaparte's gulls disclosed a high degree of salinity tolerance and predilection for food items existing in ponds of high salinity. Shorebirds used ponds that were shallow enough for wading irrespective of salinity.

ACKNOWLEDGMENTS

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Food Item	Ruddy				Shoveler				Pintail		Green-winged teal		Cinnamon teal		Baldpate		Lesser scaup		Redhead	
	9/67		2/68		9/67		2/68		9/67		2/68		9/67		2/68		2/68		2/68	
	(3) Vol. %	(3) Freq.	(7) Vol. %	(7) Freq.	(2) Vol. %	(4) Freq.	(1) Vol. %	(5) Freq.	(4) Vol. %	(4) Freq.	(1) Vol. %	(1) Freq.	(1) Vol. %	(1) Freq.	(2) Vol. %	(2) Freq.	(5) Vol. %	(5) Freq.	(2) Vol. %	(2) Freq.
PLANT FOODS																				
Ruppia maritima (sds)	6.7	3	85.7	7	trace	2	trace	2	66.2	3	--	--	65.0	1	trace	1	1.0	4	trace	2
Algae (filaments)	--	--	trace	1	--	--	--	--	--	--	--	--	--	--	100.0	2	69.0	4	100.0	2
Vegetative fgmts. & fibers	--	--	--	--	60.0	4	100.0	3	5.0	1	100.0	1	35.0	1						
Hordeum vulgare	--	--	--	--	--	--	--	--	25.0	1										
Polygonum aviculare	--	--	--	--	20.0	3														
Scirpus robustus	--	--	--	1	trace	2	trace	3	2.5	2										
Potamogeton pectinatus	trace	1	--	--	trace	1	--	--	1.3	2										
Melilotus indica	--	--	--	--	20.0	3	--	--	--	--	--	--	--	--	--	1				
Cyperaceae	--	1																		
Naias marina	--	1																		
Eleocharis palustris	--	--	--	1																
Myriophyllum spicatum	--	--	--	1																
Polygonum lapathifolium	--	--	--	--	--	1	--	1												
Medicago sp.	--	--	--	--	--	1	--	--	--	1										
Heleochloa schoenoides	--	--	--	--	--	1														
Potamogeton pusillus	--	--	--	--	--	1														
Spergularia marina	--	--	--	--	--	--	--	1	--	--	--	--	--	--	--	1				
Polygonum sp.	--	--	--	--	--	--	--	2												
Rubus sp.	--	--	--	--	--	--	--	1												
Atriplex patula	--	--	--	--	--	--	--	1												
Scirpus acutus	--	--	--	--	--	--	--	1	--	1										
ANIMAL FOODS																				
Corixidae (adults, imm.)	68.3	3	14.3	1	--	3	--	--	--	2	--	--	--	--	--	--	--	1		
Nassarius obsoletus	21.7	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10.0	1		
Ephydra cinerea (larvae, puparia)	3.3	1	trace	1	--	1	--	1	--	--	--	--	--	--	--	--	20.0	1		
Ostracoda	--	--	--	1	--	1														
Lamellibranchia (shell fgmts)	--	--	--	--	--	--	--	4	--	1	--	--	--	--	--	--	--	1	--	1
Coleoptera (adult)	--	--	--	--	--	1														
Amphipoda	--	--	--	1	--	--	--	--	--	--	--	--	--	--	--	1				
Isopoda	--	--	--	--	--	--	--	--	--	1										
Polychaeta (jaws)	--	--	--	2																

NOTE: 1 Scaup collected from Pond 1 (Algae—100%).
1 Scaup collected from Pond 6 (Ephydra larvae—100%).
1 Ruddy—Pond 3 (Corixidae—100%).

APPENDIX II

Eared Grebes Food Habits on Salt Ponds
February 1968

Food or matter	Vol. %	Freq.
	(5)	(5)
Feathers	62.0	5
Unidentified matter	27.0	4
Artemia salina	8.6	4
Ephydra cinerea (larvae)	1.2	2
Ephydra cinerea (puparia)	1.0	1
Coleoptera (adult fgmts.)	0.2	1

NOTE: 5 grebes collected from Pond 6.
( ) — total sample.

APPENDIX III

Shorebirds—Food Habits on Salt Ponds

	Least sandpipers				Western sandpiper		Dunlin		Avocets				Willet		Wilson Phalarope		Northern Phalarope	
	9/67		2/68		9/67		2/68		9/67		2/68		2/68		9/67		9/67	
	(5) Vol. %	(5) Freq.	(3) Vol. %	(4) Freq.	(5) Vol. %	(6) Freq.	(9) Vol. %	(9) Freq.	(5) Vol. %	(5) Freq.	(5) Vol. %	(7) Freq.	(3) Vol. %	(3) Freq.	(5) Vol. %	(5) Freq.	(5) Vol. %	(5) Freq.
Ephydra cinerea (larvae)	trace	1	95.0	3	45.0	4	42.0	5	10.9	1	52.0	6	34.0	3	trace	1	18.0	1
Ephydra cinerea (puparia)	--	--	--	--	20.0	1	trace	3	25.2	4	trace	2	trace	1	16.0	3		
Corixidae (adults, imm., eggs)	30.0	3	trace	3	--	--	trace	3	10.4	3	trace	1	--	--	73.0	5	82.0	5
Coleoptera (adults)	20.0	1	5.0	2	--	--	trace	2										
Diptera (adults)	20.0	2	--	--	trace													
Insecta (larvae, pupae) (unid.)	10.0	2	trace	1	10.0		--	--	--	--	--	--	--	--	trace	2		
Worm cases (Polychaeta)	--	--	--	--	--	--	--	--	--	--	--	--	51.7	2				
Mud tubes (Polychaeta)	--	--	--	--	--	--	--	--	20.0	1								
Polychaeta (worms, jaws)	trace	1	--	--	trace	1	0.1	4	trace	1								
Lamellibranchia (*Macoma, Gemma, Mytilis*)	--	--	trace	3	--	--	41.4	8	8.0	2	--	--	0.3	1				
Gemma gemma	--	--	--	--	--	--	11.1	1										
Gastropoda	--	--	trace	1	--	--	3.3	4	--	--	--	--	14.0	2				
Artemia salina	--	--	--	--	--	--	--	--	--	--	48.0	6	--	--	9.0	1		
Amphipoda	--	--	--	--	--	--	1.9	4										
Ostracoda	--	--	--	--	--	--	0.2	1										
Arachnidae	--	--	trace	1														
Dytiscidae (larvae)	--	--	--	--	--	--	trace	1										
Ruppia maritima (sds)	20.2	2	--	--	25.0	3	trace	1										
Vegetative stem fgmts & fibers	--	--	--	--	--	--	--	--	26.4	5								
Scirpus acutus (sds)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.0	1		

NOTE: 5 Dunlin (2/68) collected from Pond 6.
4 Dunlin (2/68) collected from Pond 1.
3 Willet (2/68) collected from Pond 3.
7 Avocet (2/68) collected from Pond 6.
4 L. Sandpiper (2/68) collected from Pond 6.

APPENDIX IV

Checklist of Birds in the Salt Pond Study

Grebes

Eared grebe *Podiceps caspicus*
Pied-billed grebe *Podilymbus podiceps*

Pelicans

White pelican *Pelecanus erythrorhynchos*

Cormorants

Double-crested cormorant *Phalacrocorax auritus*

Egrets

Great blue heron *Ardea herodias*
Common egret *Casmerodius albus*
Snowy egret *Leucophoyx thula*
Black-crowned night heron *Nycticorax nycticorax*

Geese

Snow goose *Chen hyperborea*
Ross's goose *Chen rossii*

Puddle Ducks

Mallard *Anas platyrhynchos*
Gadwall *Anas strepera*
Pintail *Anas acuta*
Green-winged teal *Anas carolinensis*
Cinnamon teal *Anas cyanoptera*
American widgeon *Marcca americana*
Shoveler *Spatula clypeata*

Diving Ducks

Redhead *Aythya americana*
Canvasback *Aythya ralisineria*
Greater scaup *Aythya marila*
Lesser scaup *Aythya affinis*
Common goldeneye *Bucephala clangula*
Bufflehead *Bucephala albeola*
Ruddy duck *Oxyura jamaicensis*
Red-breasted merganser *Mergus serrator*
Coot *Fulica americana*

Shorebirds

Semi-palmated plover *Charadrius semipalmatus*
Snowy plover *Charadrius alexandrinus*
Killdeer *Charadrius vociferus*
Black-bellied plover *Squatarola squatarola*
Black turnstone *Arenaria melanocephala*
Long-billed curlew *Numenius americanus*
Whimbrel *Numenius phaeopus*
Willet *Catoptrophorus semipalmatus*
Greater yellowlegs *Totanus melanoleucus*
Lesser yellowlegs *Totanus flavipes*
Knot *Calidris canutus*
Least sandpiper *Erolia minutilla*
Dunlin *Erolia alpina*
Short-billed dowitcher *Limnodromus griseus*
Western sandpiper *Ereunetes mauri*
Marbled godwit *Limosa fedoa*
Avocet *Recurvirostra americana*
Black-necked stilt *Himantopus mexicanus*

Phalaropes

Wilson's phalarope *Steganopus tricolor*
Northern phalarope *Lobipes lobatus*

Gulls

Glaucous-winged gull *Larus glaucescens*
Herring gull *Larus argentatus*
California gull *Larus californicus*
Ring-billed gull *Larus delawarensis*
Bonaparte's gull *Larus philadelphia*

Terns

Forster's tern *Sterna forsteri*
Least tern *Sterna albifrons*
Caspian tern *Hydroprogne caspia*
Black tern *Chlidonias niger*

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SPAWNING BED SEDIMENTATION STUDIES IN NORTHERN CALIFORNIA STREAMS[1]

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Changes in the size composition of spawning bed materials in six coastal streams were monitored for 3 years to determine the effects of logging on the habitat of silver salmon (*Oncorhynchus kisutch*) and trout (*Salmo gairdnerii gairdnerii* and *S. clarkii clarkii*). Four test streams were sampled before, during and after logging. Two streams in unlogged watersheds and the undisturbed upstream section of one test stream served as controls. A variety of stream types in second-growth and old-growth forests was selected for observation.

Spawning bed composition in the four test streams changed after logging, roughly in proportion to the amount of streambank disturbance. The heaviest sedimentation occurred when bulldozers operated in narrow stream channels having pebble bottoms. In a larger stream with a cobble and boulder bottom, bulldozer operations in the channel did not increase sedimentation greatly. Sustained logging and road construction kept sediment levels high in one stream for several years. Sedimentation was greatest during periods of road construction near streams and removal of debris from streams, confirming the need for special measures to minimize erosion during such operations. Control streams changed little in spawning bed composition during the 3 years.

INTRODUCTION

The condition of a streambed has important implications for salmon and trout production. These fish deposit their eggs and their young find food and shelter among the streambed gravels. Excessive sediment decreases productivity by smothering or crowding out the organisms living in the streambed (Cordone and Kelley, 1961). Incubating salmonid embryos and fry are particularly susceptible to sedimentation. Fine particles deposited in the streambed render redds less permeable (McNeal and Ahnell, 1964), impede fry emergence (Hall and Lantz, 1969), and may, by reducing oxygen levels in the riffles, cause high mortality and poor fry quality at emergence (Mason, 1969).

Logging has been recognized as a major cause of sediment in California streams (Calhoun, 1967); however, quantitative data on the accrual of fine sediments in spawning gravels are scarce, since most sedimentation work has concentrated on increases in suspended solids (U. S. Dept. Agriculture, 1965; Peters, 1967). Stream sedimentation in Alaska was temporary when reasonable habitat protection accompanied logging operations (Sheridan and McNeil, 1968). However, the results of work in other states are not generally applicable to California because of differences in climates, soils, forests and logging techniques. Therefore, in 1966 the California Department of Fish and Game began monitoring the effects of logging on silver salmon (*Oncorhynchus*

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kisutch) and trout (*Salmo gairdnerii gairdnerii* and *S. clarkii clarkii*) habitat in the redwood (*Sequoia sempervirens*) and Douglas fir (*Pseudotsuga Menziesii*) forests of northwestern California. This report describes changes in spawning bed composition accompanying logging and associated road building.

LOCATION AND DESCRIPTIONS OF STUDY STREAMS AND LOGGING OPERATIONS

Seven stream sections on six small watersheds were chosen for study (Table 1). Four of the seven were logged using methods specific to their locales. The other three remained undisturbed and served as experimental controls. Soils in these drainages are predominately loamy and moderately erodable. Heavy winter rainfall and dry summers explain the large variations in streamflow. Air temperatures along the coast are cooled by dense, recurrent fogs.

Control Streams

The old growth redwood forest of Godwood Creek, Humboldt County, lies within Prairie Creek State Park. This stream drains into the Redwood Creek system. South Fork Yager Creek, Humboldt County, flows through private lands and is part of the Eel River system. Its drainage basin has no history of logging. The forest is old-growth Douglas fir and redwood. North Fork Caspar Creek, Mendocino County, lies within Jackson State Forest. Its redwood-Douglas fir forest was logged about 100 years ago. Caspar Creek enters the ocean south of Fort Bragg.

Test Streams

Bummer Lake Creek, Del Norte County, flows through private lands into the Smith River. One hundred and ten hectares (272 acres) of its old-growth forest were clear cut in alternate blocks on the southwest side of the stream in 1968. Redwood and Douglas fir logs were hauled by high lead away from the stream up to the road, and by bulldozer above the road. The average horizontal distance between the stream and the road was 120 m (400 ft) and there were no stream crossings. Fifty-eight thousand m^3 (25 million board feet) of timber were harvested. A bulldozer operated in the streambed to remove logs and other debris from the 1,524-m study section.

South Fork Yager Creek, Humboldt County, was divided into two equal sections. The test section extended from the mouth 560 m (1,835 ft) upstream to the lower end of the unlogged control section. Douglas fir and redwood were selectively cut to 305 m (1,000 ft) on each side of the test section in 1968. Great care was taken to protect the stream; riparian vegetation (including harvestable timber leaning toward the stream) was not cut and equipment did not enter the stream. Eighty percent of the timber volume was cut from the original 344 m^3/hectare (60,000 board feet/acre). Roads were built away from the stream on low gradient slopes.

Little North Fork Noyo River, Mendocino County, flows through private lands into the Noyo River. Its redwood-Douglas fir forest, logged about 100 years ago, has been subjected to periodic road construction

TABLE 1

Stream and Watershed Characteristics Prior to Logging

	Bummer Lake Creek	Godwood Creek	S. Fork Yager Creek	Little N. Fork Noyo River	N. Fork Caspar Creek	S. Fork Caspar Creek
Status	Logged 1968	Old growth, unlogged	Logged 1968	Logged 1966–69	Second growth, unlogged	Road construction 1967
Study section length, m (ft)	1,524 (5,000)	3,110 (10,196)	1,119 (3,670)	1,530 (5,016)	2,459 (8,061)	3,093 (10,142)
Drainage area, ha (acres)	1,400 (3,456)	467 (1,152)	2,514 (6,208)	989 (2,432)	508 (1,255)	425 (1,050)
Avg canyon slope, percent	45	18	38	36	45	49
Avg stream slope, percent	5	1	4	3	2	3
Avg stream width, m[1] (ft)	4.9 (16)	3.1 (10)	5.2 (17)	1.5 (5)	1.8 (6)	1.8 (6)
Soil series[2]	Melbourne	Melbourne	Hugo	Hugo	Hugo	Hugo
Major streambed surface[3]	cobble and boulder	pebble	cobble and boulder	pebble	pebble	pebble
Mean annual precipitation,[4] cm (inches)	203 (80)	152 (60)	102 (40)	127 (50)	127 (50)	127 (50)
Annual streamflow range,[5] m^3/sec (cfs)	0.014–1.4 (0.5–50)	0.023–0.37 (0.8–13)	0.008–0.93 (0.3–33)	0.002–0.40 (0.08–14)	0.001–0.23 (0.05– 8)	0.002–0.25 (0.06– 9)

[1] Summer average minimum.
[2] Storie and Weir (1953).
[3] Wentworth's classification (Welch, 1948).
[4] Durenberger (1960).
[5] Range observed during water quality sampling in 1968–69 (Kopperdahl and Burns, 1970). Only two streams have streamflow gages and their recorded ranges exceed those observed during water quality sampling: N. Fork Caspar Creek usually reaches 13.0 m^3/sec (46 cfs) in the winter and S. Fork Caspar Creek generally reaches 11.9 m^3/sec (42 cfs) (Ziemer, Kojan, Thomas and Muller, 1966).

and selective logging since 1964. Thirty percent of the timber volume has been removed from 542 hectares (1,338 acres) of watershed since 1966. A bulldozer worked in or near the 1,530-m study section during road construction and right-of-way logging in 1966 and 1969. Average road distance to the stream was about 23 m (75 ft). There was one bridge crossing at the upper end of the study section.

South Fork Caspar Creek, like the North Fork, is in Jackson State Forest and is managed by the California Division of Forestry. Its redwood-Douglas fir forest was also logged about 100 years ago. In 1967, 76,400 m^3 (100,000 cubic yards) of road materials were removed and 10,000 m^3 (4.3 million board feet) of timber harvested along 5.96 km (3.7 miles) of road right-of-way construction. The road was built adjacent to the stream, ranging from four bridge crossings to 76 m (250 ft) from the stream. Road materials were side-cast into the stream and one part of the stream was relocated during road construction. A bulldozer operated through 41% of the 3,093-m study section during debris removal. Most of the fill slopes, secondary roads and streambank were fertilized with urea and seeded with annual rye grass (*Elymus* sp.), at a rate of 56 kg/hectare (50 lbs/surface acre) (David Burns, Calif. Div. of Forestry, pers. comm.). This grass was well established before the first winter after road construction and again by the second winter. No logging trucks used the road during or after the first winter.

METHODS

The four test streams were sampled from 1966 through 1969, before, during and after logging, to measure changes in spawning bed composition which accompanied specific logging practices. Surveys were systematic so that the entire stream section was examined and most of the spawning beds sampled. The three control streams were sampled during the same general period. Usually 20 bottom samples were taken from each stream during each survey.

Surveys were made in the summer and fall when streamflow was stable and low enough to permit sampling. Samples were taken with a 15.24 cm (6-inch) diameter stainless steel cylinder similar to the one described by McNeil and Ahnell (1964), but with a plunger rather than a cap to retain suspended sediments. Each sample was taken to a depth of 15.24 cm in the center of the stream near the head of a riffle. This location was chosen as representative of the areas in which salmonoids spawn.

Tyler screens with openings of 26.67 mm (1.050 inch), 3.327 mm (0.131 inch), and 0.833 mm (0.0328 inch) were used to separate the samples into four size classes, three of which were retained by the screens, while the fourth passed through the 0.833 mm screen. Volumes for those classes retained were measured by water displacement. The fraction passing the 0.833 mm screen was measured after settling in a graduated cylinder for 10 minutes.

These size classes were selected because past studies have defined their effects on embryo and fry survival. Generally, survival is lower as the volume of materials less than 25 mm diameter increases (Shelton, 1955; MacKinnon, 1960; Phillips, 1963). Specifically, materials from 1 to 3 mm impede fry emergence (Phillips, Campbell, Hug and Claire,

1966; Lantz, 1967; Hall and Lantz, 1969; Phillips and Koski, 1969); and sediments smaller than 0.8 mm greatly reduce streambed permeability (McNeil and Ahnell, 1964; Koski, 1966), as do sediments smaller than 3.4 mm (Cooper, 1965).

The volume of each size class of materials was converted to a percentage of each streambed sample. These percentages were averaged to obtain the mean percentage of the total sample volume passing each sieve. Differences between streams were tested at the 5% significance level using Student's t-test (Burns, 1966).

CHANGES IN SPAWNING BED COMPOSITION OF UNLOGGED STREAMS

The size composition of the spawning bed materials remained fairly stable in Godwood and North Fork Caspar creeks during the 3 years of study (Tables 2 and 3). The amount of sediment smaller than 0.8 mm changed less than 1% in Godwood Creek. Materials smaller than 3.3 mm changed less than 8%, and those smaller than 26.7 mm less than 10%. Similar differences were observed in the North Fork Caspar Creek, except in 1969 when the mean percentage of materials less than 0.8 mm diameter was 5.2% greater than the average for the previous 2 years. This difference was not statistically significant, however. Heavier storms in the 1969 water year probably increased erosion in this relatively unstable watershed; in addition, there was a greater total precipitation in 1969 (148 cm) than in 1968 (105 cm). The deposition of sediments behind the North Fork Caspar Creek weir was 630% greater in 1969 than in 1968, indicating much greater streambed movement in 1969 (Jay S. Krammes, U. S. Forest Service, pers. comm.).

TABLE 2

Size Composition of Spawning Bed Materials in Godwood Creek, Humboldt County, California

Date	Mean percentage of total sample volume*			Number of samples
	Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
July 1967	**17.3** (13.2–21.3)	**30.3** (24.5–36.2)	**70.2** (64.2–76.2)	20
July 1968	**17.8** (14.3–21.2)	**37.9** (33.1–42.7)	**79.6** (74.0–85.3)	20
July 1969	**17.7** (14.3–21.2)	**30.9** (26.2–35.6)	**73.5** (65.5–81.4)	20

* 95% confidence intervals in parentheses.

The unlogged portion of South Fork Yager Creek also showed a large, but not statistically significant increase in the volumes of sediment less than 0.8 mm and less than 3.3 mm (Table 4). For materials smaller than 0.8 mm the increase was 5.7% and for materials less than 3.3 mm the increase was 16.3%. In 1969 there was a significant increase (19.8% greater than in 1967) in the volume of materials smaller

TABLE 3

Size Composition of Spawning Bed Materials in North Fork Caspar Creek, Mendocino County, California

Date	Mean percentage of total sample volume*			Number of samples
	Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
June 1967	**18.4** (16.0–20.7)	**32.0** (28.8–35.1)	**72.0** (67.4–76.6)	20
Oct. 1967	**17.5** (14.4–20.6)	**33.5** (28.5–38.6)	**79.5** (75.5–83.4)	20
June 1968	**18.2** (14.5–21.9)	**34.6** (30.4–38.8)	**78.0** (73.7–82.3)	20
Oct. 1968	**18.0** (15.6–20.4)	**35.5** (32.4–38.7)	**75.7** (72.8–78.6)	20
Aug. 1969	**23.2** (20.1–26.2)	**40.5** (35.5–45.5)	**80.4** (73.6–87.2)	20

* 95% confidence intervals in parentheses.

than 26.7 mm. A portion of a tree jam and rock barrier immediately upstream from the control section collapsed during the 1968-69 winter. Deposition of sediments which had accumulated behind this barrier accounted for the increase.

TABLE 4

Size Composition of Spawning Bed Materials in the Unlogged Control Section of South Fork Yager Creek, Humboldt County, California

Date	Mean percentage of total sample volume*			Number of samples
	Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
August 1967	**16.4** (13.2–19.6)	**36.1** (28.5–43.7)	**75.4** (65.1–85.8)	10
August 1968	**17.3** (13.7–20.9)	**44.7** (36.2–53.3)	**86.2** (77.2–95.1)	10
August 1969	**22.1** (18.1–26.0)	**52.4** (40.4–64.4)	**95.2** (91.0–99.5)	10

* 95% confidence intervals in parentheses.

CHANGES IN SPAWNING BED COMPOSITION IN TEST STREAMS

Sediment of all size classes increased slightly after logging in Bummer Lake Creek, although differences were not statistically significant (Table 5). They were also within the range of natural change

observed in the control streams. Such a small increase was unexpected, since bulldozers had operated extensively in the clear cut areas and in the stream channel during debris removal. The boulders and cobbles composing the streambed and the wide stream channel (Figure 1) apparently kept the bulldozer from gouging the stream banks.

The logged section of South Fork Yager Creek exhibited streambed composition changes like those in the upstream control section (Table 6). The only statistically significant change was an increase in the class of sediments smaller than 26.7 mm, which occurred in both the test and the control sections. Release of sediments following collapse of the upstream barrier mentioned earlier adequately explains this change. I did not expect sedimentation to increase after logging in South Fork Yager Creek, since neither the stream channel nor the watershed was appreciably disturbed by bulldozer operations, which were conducted with unusual care.

Following construction of an all weather road in the winter of 1966-67, the percentage of sediments smaller than 0.8 mm increased significantly in the Little North Fork Noyo River (Table 7). By 1968 these sediments had increased 11%. In 1969, after a second road was constructed on the other side of the stream, sediments smaller than 0.8 mm increased to 13.3% over the predisturbance level. Much sediment entered the stream in 1968 through road slippage. In 1969, however, most sediment resulted from bulldozer operations in the lower stream (Figure 2). Small materials composing the narrow streambed and bank were deeply gouged by the bulldozer, leaving a heavily silted streambed with a channel consisting of bulldozer tracks.

The volume of sediments smaller than 0.8 mm in South Fork Caspar Creek increased 13.6% immediately after road construction (Table 8). The next summer it returned to the predisturbance level. Twenty-two months later, however, the small sediments were 8.8% higher than the predisturbance level. The initial increase in 1967 followed extensive use of a bulldozer to clear the stream of logging debris. The narrow streambed composed of small materials was particularly susceptible to degradation (Figure 3). Erosion was minimized the first winter by establishing annual rye grass on the stream banks, fill-slopes and skid trails (Figure 4). Without additional erosion, accumulated sediments were scoured from the riffles. The increase in 1969 was probably caused by streambank erosion and two winters of erosion on side casts and slides. Erosion from only a fraction of a logged area can pollute an entire stream (Lull and Reinhart, 1965). The winter storms of the 1968 water year were mild (total annual precipitation: 98 cm) compared with the heavier storms and greater total precipitation (142 cm) for the 1969 water year. Heavier rainfall could have accounted for increased erosion. Moreover, there was less rye grass to hold the soil in place in disturbed areas than there had been the first winter. Bed load movement within the stream was also greater in 1969 than in 1968. There was a 73% increase in the amount of sediment deposited behind the South Fork weir in 1969 (Jay S. Krammes, U. S. Forest Service, pers. comm.). Road slides were common in both winters and repair was necessary each spring. Road slides also play an unpredictable but important role in sedimentation (Fredrickson, 1965).

TABLE 5

Size Composition of Spawning Bed Materials in Bummer Lake Creek, Humboldt County, California

Date	Condition	Mean percentage of total sample volume*			Number of samples
		Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
Sept. 1967	Unlogged	**10.2** (8.1–12.2)	**28.0** (24.5–31.6)	**73.0** (66.5–79.5)	21
Sept. 1968	Two months after logging	**11.7** (9.6–13.8)	**30.7** (26.8–34.7)	**76.8** (70.4–83.2)	21
Sept. 1969	Fourteen months after logging and 11 months after stream cleanup	**13.3** (11.1–15.5)	**31.3** (27.4–35.3)	**82.5** (78.5–86.5)	21

* 95% confidence intervals in parentheses.

TABLE 6

Size Composition of Spawning Bed Materials in the Test Section of South Fork Yager Creek, Humboldt County, California

Date	Condition	Mean percentage of total sample volume*			Number of samples
		Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
August 1967	Unlogged	**16.4** (12.7–20.1)	**40.1** (34.2–45.9)	**76.0** 67.5–84.5))	10
August 1968	Immediately after logging	**16.5** (11.8–21.2)	**39.9** (29.6–50.3)	**78.9** (65.6–92.2)	10
August 1969	Twelve months after logging	**23.6** (16.9–30.3)	**54.8** (44.3–65.4)	**95.2** (90.9–99.5)	10

* 95% confidence intervals in parentheses.

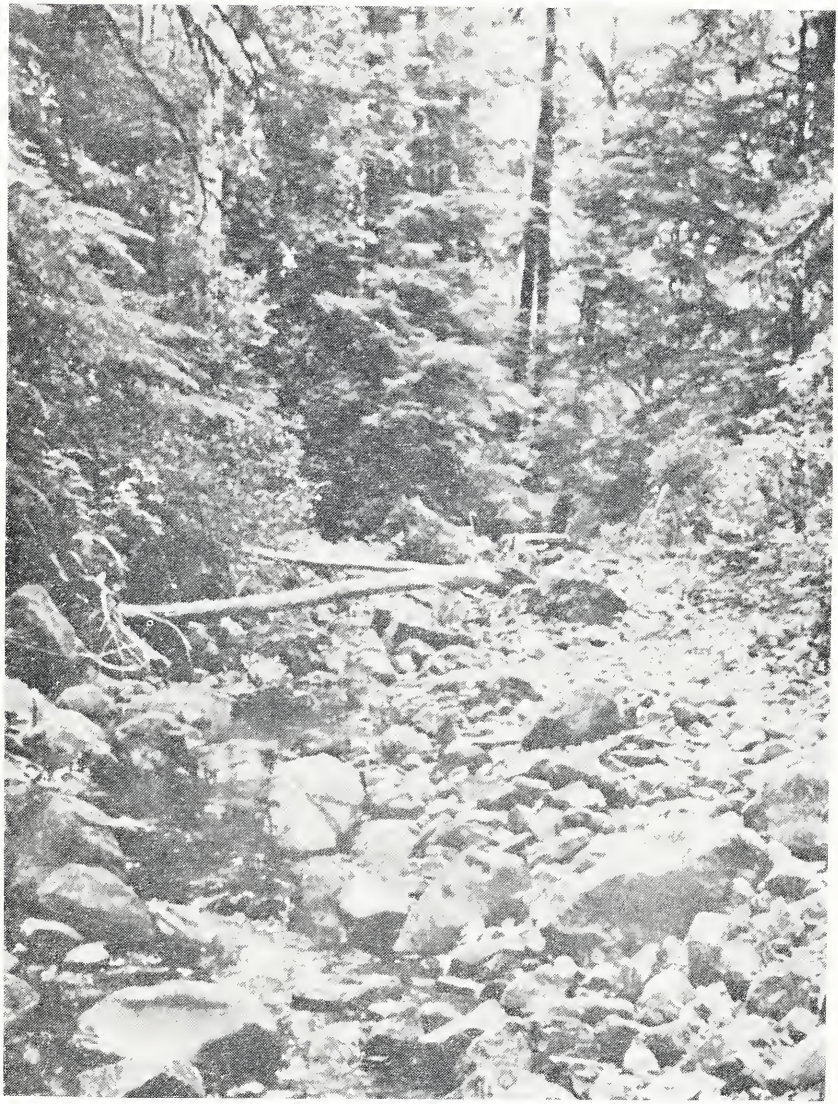

FIGURE 1—Bummer Lake Creek, Del Norte County, before logging, 1967. Boulder and rubble-sized materials made up the streambed. *Photograph by Michael Moore.*

TABLE 7

Size Composition of Spawning Bed Materials in Little North Fork Noyo River, Mendocino County, California

Date	Condition	Mean percentage of total sample volume*			Number of samples
		Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
Oct. 1966	Second growth forest, pre-road construction	**20.0** (17.7–22.2)	**NR**†	**84.7** (80.5–88.8)	27
Oct. 1968	Twenty-four months after initial road construction and 12 months after gully logging	**31.0** (23.6–38.3)	**42.1** (33.3–50.8)	**81.3** (73.6–89.0)	8
Sept. 1969	Immediately after second road construction	**33.3** (25.1–41.5)	**44.4** (36.6–52.2)	**86.2** (81.0–91.3)	16

* 95% confidence intervals in parentheses.
† NR = The 3.3 mm sieve was not used in 1966.

FIGURE 2—Little North Fork Noyo River, Mendocino County, immediately after logging debris removal, 1969. The stream's course was formed by bulldozer tracks. *Photograph by the author.*

TABLE 8

Size Composition of Spawning Bed Materials in South Fork Caspar Creek, Mendocino County, California

Date	Condition	Mean percentage of total sample volume*			Number of samples
		Less than 0.8 mm	Less than 3.3 mm	Less than 26.7 mm	
June 1967	Second growth forest, pre-road construction	**20.6** (17.8–23.4)	**36.4** (32.3–40.6)	**73.3** (68.6–77.9)	20
Oct. 1967	Immediately after road construction	**34.2** (25.6–42.8)	**47.8** (38.6–57.1)	**77.8** (71.5–84.2)	20
June 1968	Eight months after completion	**17.9** (10.9–24.9)	**37.2** (29.6–44.9)	**84.4** (79.4–89.5)	19
Oct. 1968	Twelve months after completion	**19.0** (14.8–23.2)	**37.1** (31.8–42.5)	**74.8** (68.2–81.4)	20
Aug. 1969	Twenty-two months after completion	**28.5** (24.6–32.3)	**44.2** (39.8–48.5)	**75.0** (69.8–80.2)	20
Sept. 1969	Twenty-three months after completion	**27.1** (23.7–30.5)	**40.8** (35.7–45.8)	**75.7** (71.0–80.5)	19

* 95% confidence intervals in parentheses.

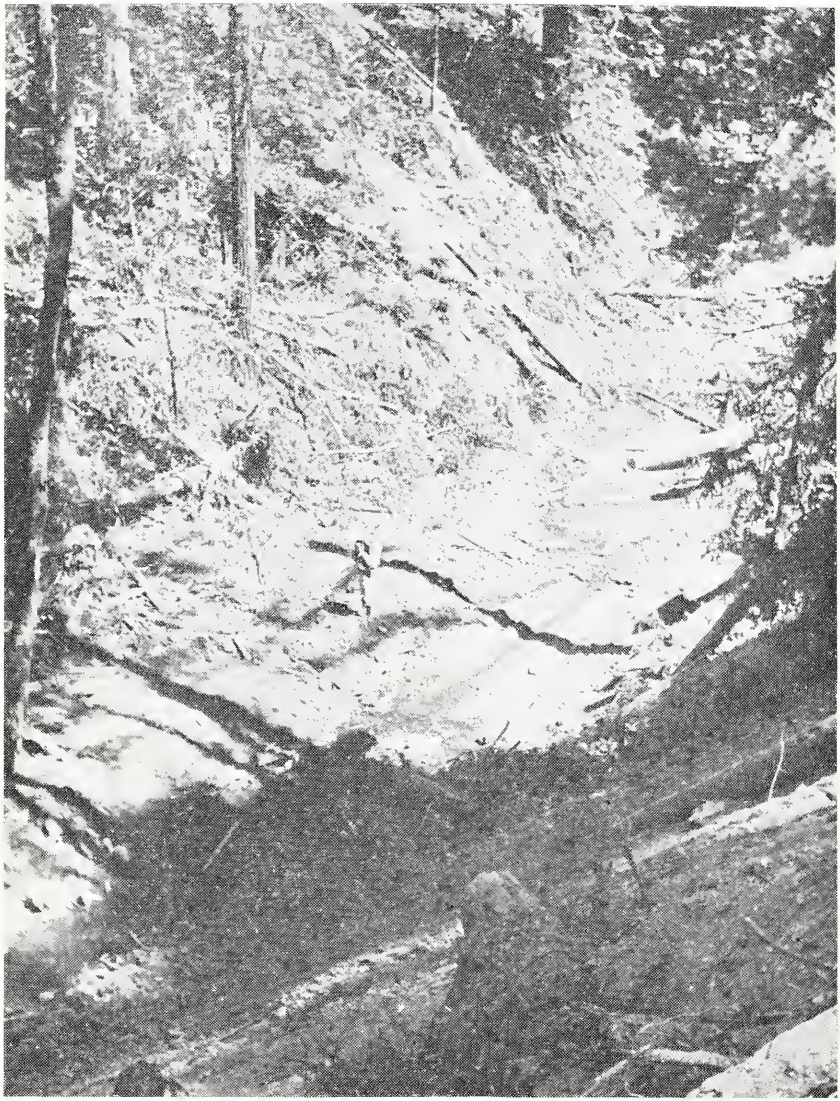

FIGURE 3—South Fork Caspar Creek, Mendocino County, immediately after road construction in 1967. A bulldozer operated extensively in the stream channel and materials from road building slid into the stream. *Photograph by Paul Hubbell.*

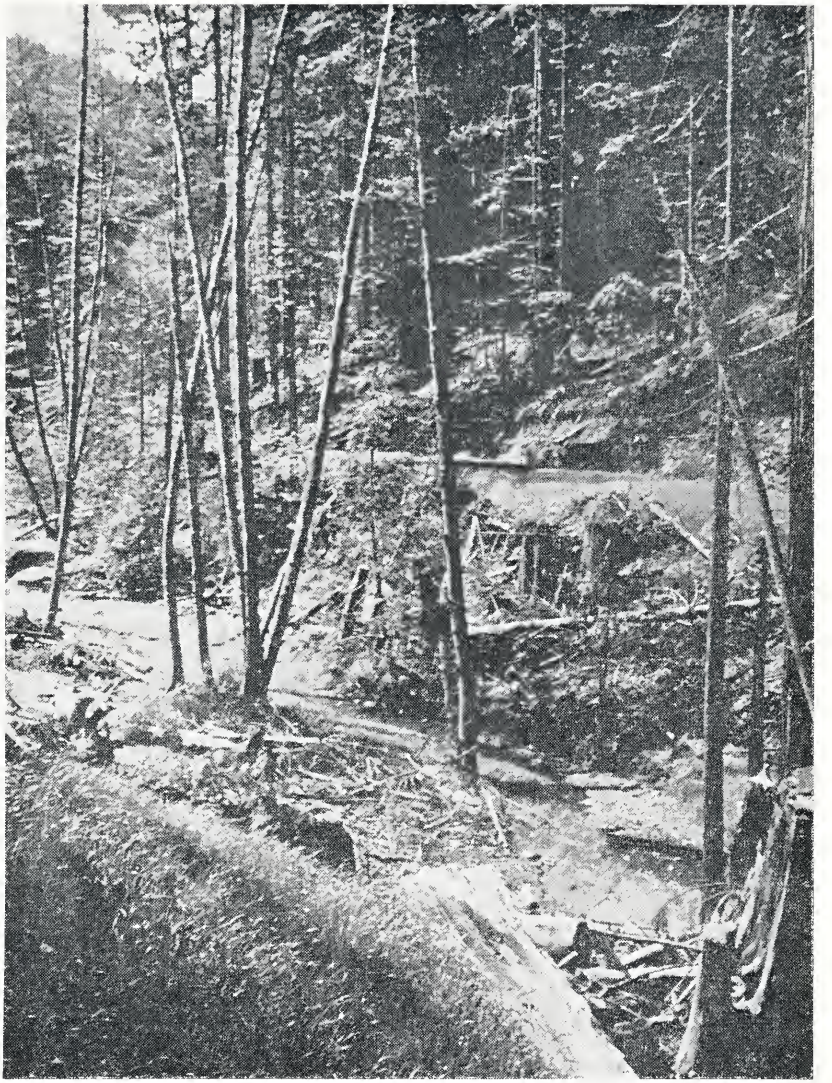

FIGURE 4—Annual rye grass was well established on the stream banks, fill-slopes and skid trails of South Fork Caspar Creek, Mendocino County, by the first winter after logging. *Photograph by Paul Hubbell.*

DISCUSSION AND CONCLUSIONS

Changes in spawning bed composition need not be gross to affect fry survival. For example, in Deer Creek, Alsea drainage, Oregon, an increase in materials smaller than 0.8 mm of only 5% (from 20 to 25%) caused a 19% decrease in the survival to emergence of silver salmon fry (Hall and Lantz, 1969). Since I did not measure survival to emergence or spawning bed composition during incubation, it was not pos-

sible to relate the observed changes in sediment composition to fry survival for California streams. The relationships are probably similar to those found in Oregon. I did measure, however, summer standing crops of juvenile salmonids in the streams. This will be the subject of a later report (Burns, in preparation).

Sampling during the low flow periods of late spring and summer may not have reflected conditions during incubation. For example, a layer of silt could have been deposited on the spawning bed, cutting off intragravel flow and dissolved oxygen delivery, and then washed out, leaving no evidence of its former presence. Even when turbulence prevents deposition of fine materials on the streambed surface, deposition may still occur within the gravels (Cooper, 1965). Because of seasonal variations in Alaskan streams, investigators there used summer samples for long-term comparisons (Sheridan and McNeil, 1968). I assumed that this sampling period would also be adequate for my long-term comparisons. Furthermore, it is very difficult to sample during high water and the probability of destroying redds during intensive sampling is quite high.

All streams increased somewhat in fine sediments during the 3-year study, although logged streams increased the most. Unlogged Alaskan streams have fluctuated about 7% in the 0.8 mm class (Sheridan, Hoffman and Olson, 1965). Unlogged California streams have fluctuated even less. For example, Godwood and North Fork Caspar creeks changed less than 1% in this size class in 3 years, while the control section of South Fork Yager Creek changed 5.7%. The greatest increase observed in the logged streams was 13.6% (South Fork Caspar Creek). However, none of the four logged streams received extensive watershed disturbance. Except for the Little North Fork Noyo River, the logging operation was limited to one season. Furthermore, the disturbances were restricted to a small fraction of the total watershed. Heavy sedimentation might have been the rule rather than the exception if these watersheds had been heavily cut or subjected to sustained logging over a longer period. These results, however, provide a base for future comparisons, after these same watersheds are logged more extensively.

My studies suggest that different streams may be affected differently by bulldozer activities. Narrow ones (Little North Fork Noyo River and South Fork Caspar Creek) with small gravel or pebble bottoms were adversely affected by bulldozer operations in the stream. The largest stream (Bummer Lake Creek), with a cobble and boulder bottom was not as easily gouged and eroded.

Road location is another important consideration in streambed sedimentation. Roads on low gradient slopes or located more than 30 m (100 ft) from the stream generally did not contribute to spawning bed sedimentation. Turbid runoff from these roads usually sank into the forest floor before reaching the stream. Roads located close to a stream usually feed sediment directly into the channel and streambed (Lull and Reinhart, 1965).

Spawning bed recovery may be rapid or may take several years. The riffles in streams with relatively stable flows generally accumulate sediments more readily than those with very high peak flows. Fine sediments are readily flushed out by freshets once the source of erosion

is removed (McNeil and Ahnell, 1964; Shapley and Bishop, 1965; Saunders and Smith, 1965); however, continuing disturbances, such as occurred in building another road along the Little North Fork Noyo River, prolonged sedimentation. Ideally, logging operations in a watershed should be completed as soon as possible (Lull and Reinhart, 1965). Anderson and Richards (1961) found that once logging was completed in a small Sierra Nevada watershed, suspended solids markedly decreased from those concentrations observed during logging. Most of the sedimentation I observed occurred during road construction and removal of debris from the streams, suggesting that special attention should be paid to erosion control during such operations.

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HARVEST OF FOUR STRAINS OF RAINBOW TROUT, *SALMO GAIRDNERII*, FROM BEARDSLEY RESERVOIR, CALIFORNIA[1]

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Four strains of rainbow trout, a wild strain of Kamloops rainbow and three domestic strains utilized in California's catchable trout program, were planted as fingerlings in Beardsley Reservoir, Tuolumne County, from 1961 through 1966. Kamloops and Shastas, the most recently developed domestic strain, were decidedly superior to Whitneys and Virginias, two strains domesticated since near the turn of the century. The best time of the year to plant Kamloops was in April and May when they were 1.0 to 3.2 per ounce. Shastas planted in July and August from 2.5 to 6.2 per ounce were most successful. Comparing groups of these strains planted only at these times we found that Kamloops were harvested at a significantly higher rate than Shastas. Shastas, however, had a higher average ratio of pounds caught to pounds planted, and a lower average cost per pound in the creel.

Kamloops displayed a greater tendency to leave the reservoir during periods of spillway discharge, and were less available to shore anglers than the domestic strains. Moreover, they were more difficult to raise in the hatchery. The performance of Shastas we believe, could be greatly improved if they were available for planting at a larger size in the spring.

INTRODUCTION

Water developments in California have created numerous large, fluctuating coldwater reservoirs. A large portion of the State's trout fishing effort is expended on these waters. In many of them, fishing is either unsatisfactory or highly variable from year to year. A major cause of poor fishing is inadequate natural recruitment from the tributaries. Consequently, the fisheries depend upon annual planting of large numbers of fingerling rainbow trout.

In 1961, the California Department of Fish and Game initiated the Coldwater Reservoir Study to evaluate various fisheries management practices on coldwater reservoirs and to define the characteristics of coldwater reservoirs that affect fish production. The initial objective was to determine the best strain of trout for planting in such waters. This report summarizes results of stocking one wild strain and three domesticated strains of rainbow trout in Beardsley Reservoir, Tuolumne County, from 1961 through 1966. The three domestic strains used in this report were the Virginia, the Whitney, and the Shasta. The Kamloops was the single wild strain studied.

Beardsley Reservoir

Beardsley Reservoir (Figure 1) was formed in 1957 by an earth and rock dam on the Middle Fork Stanislaus River in Tuolumne County,

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[2] Presently on leave of absence with the United Nations Food and Agriculture Organization, Jinga, Uganda.

California. It lies on the west slope of the Sierra Nevada at an elevation of 3,397 ft. Its maximum surfaee area covers 720 aeres, and it impounds a total of 97,800 aere-feet of water, with approximate maximum and mean depths of 273 and 135 ft, respeetively. The drainage area is 309 square miles.

FIGURE 1—Beardsley Reservoir, Tuolumne County, viewed from top of dam looking east.

Total annual fluetuation in Beardsley Reservoir from 1958 through 1967 averaged 106 vertical feet (range: 72 to 135 ft). The minimum operating level of 3,261 ft above mean sea level was approached during several years but only for relatively brief periods. At this point, the reservoir capaeity is 19,903 aere-feet with a surface area of about 420 aeres.

An electrie power plant loeated at the base of the dam is operated year around. Water is drafted almost eontinuously at the rate of from 550 to 625 cfs. The point of withdrawal is about 252 ft below the maximum operating level (3,397 ft msl). A small afterbay just downstream from the dam regulates the outflow from the power plant into the river. It is about one mile long, has a capacity of 320 aere-feet, and a surface area of 26 acres.

The limnology of Beardsley Reservoir is described by Nieola and Borgeson (1970). In general, it has the attributes of a moderately oligotropic lake. A wild brown trout (*Salmo trutta*) population and a small wild population of rainbow trout exist, along with dense non-game fish populations. The most abundant non-game fishes are the western sueker (*Catostomus occidentalis*) and the hitch (*Lavinia exilicauda*).

A single major aeeess road leads to the reservoir. A cheek station was established on this road, and here a census clerk interviewed all anglers leaving the reservoir.

The Beardsley Reservoir Fishery

Fishing at Beardsley occurred each year only during the general statewide trout season, from the Saturday nearest May 1 through October 31. The characteristics of the Beardsley fishery will be detailed in a later report. Only the general characteristics are summarized here. From 1962 through 1967 an average of 6,012 anglers fished a total of 29,971 hr per year, harvesting an average of 8,163 trout. The average annual catch per hour of trout was 0.27. Fishing success is generally highest during May, September and October.

Nearly 77% of the annual effort is expended by boat anglers, who catch about 85% of all trout harvested. Of the average total annual catch, 90.7% by weight and 93.6% by number are marked rainbow trout of known hatchery origin. The remainder are wild rainbow and brown trout.

DESCRIPTION OF RAINBOW STRAINS

Virtually all domesticated rainbow brood stocks originated from rainbow taken at the old U. S. Fish Commission Hatchery on the McCloud River at Baird, California (Dollar and Katz, 1964). This trout, distributed so widely throughout North America and elsewhere in the world, is probably the result of mixing resident rainbow and anadromous steelhead rainbow (*Salmo gairdneri gairdneri*), according to Needham and Behnke (1962). Existing brood stocks, however, apparently possess characteristics unlike those of the original stock.

Virginia Strain

The Virginia strain has apparently been domesticated the longest. Its origin traces back to the Federal Wytheville Hatchery in Virginia (Dollar and Katz, 1964). Eggs first arrived at Wytheville in 1882 from the McCloud River Station. This original strain was crossed with rainbow from other sources at various times until 1930 when a selective breeding program was initiated (letter from S. A. Scott to Earl Leitritz; July 30, 1956). Virginia strain eggs were shipped to California in 1955 to meet a need for rainbow eggs during the summer, and the resulting fish were first spawned at Mt. Shasta State Hatchery in 1957. Spawning occurs from the middle of July through September with no well-defined peak. Eggs from August spawners usually hatch in late September or early October and are planted as fingerlings at about 2.5/oz in April. Sizes at different ages for this and other strains are only approximations.

Whitney Strain

A precise history of this strain is unavailable. It was developed at the Mount Whitney Hatchery, Inyo County, in the early 1900's; the exact year is not known. The first eggs came from spawners trapped in the Rae Lakes, Fresno County, in 1917. According to George McCloud (pers. comm. to A.J.C., June 10, 1968), the brood stock was developed from this source and also from rainbow from Big Bear Lake, San Bernardino County, and Lake Almanor, Plumas County. These three

populations were all derived from the original McCloud stock. However, at various times in the past, the brood stock probably was crossed with both steelhead rainbow from the Eel River and Lahontan cutthroat (*Salmo clarkii henshawi*) from Lake Tahoe. The original spring spawning time has been retained, with spawning extending from March through May, and peaking in early April. Whitneys hatch in early June, and are planted as fingerlings in September at about 3/oz. Whitneys generally have comprised the bulk of the small fingerlings stocked in California coldwater lakes and reservoirs in the summer and fall.

Shasta Strain

To obtain a winter-spawning rainbow strain, trout from Hot Creek, Mono County, were crossed with rainbow from a Federal hatchery at Meader, Idaho. The original crosses were made in California in 1951 and 1952. Initially, Shasta brood stock spawned from November through February, but as a result of further selection they now spawn almost exclusively in January and February. Peak spawning takes place in early February. Progeny from these fish are planted as fingerlings at about 4–6/oz in July, August and September.

Kamloops Strain

The Kamloops rainbow trout (*Salmo gairdneri kamloops*), native to interior waters of British Columbia, Canada, is characteristically a lake fish, spawning in tributaries, where the young spend variable amounts of time before migrating to the lake. From sources in British Columbia, Kamloops have been distributed throughout the western United States. They were introduced in California in 1950 (Wales, 1950). For this study eggs were obtained from British Columbia and from Diamond Lake, Oregon. In all cases, eggs were taken from wild Kamloops trapped during their upstream spawning migration in May and June.

Kamloops spawn from April through June with peak spawning in May. They commonly hatch in July and are planted as fingerlings either in October at about 20/oz, or in the following spring from 1-3/oz. The Kamloops not only grows more slowly than the domesticated strains but displays greater size variation.

METHODS

Trout Planting

All trout planted in Beardsley Reservoir were reared at Moccasin Creek State Hatchery near Sonora, Stanislaus County. Standard production and planting methods were employed. The trout were released from trucks a short distance from the dam.

All groups of planted trout were given distinctive marks, consisting of various combinations of excised fins and maxillary bones. The pectoral fin mark was used only in 1962. The anal fin mark was not used nor was the double ventral fin mark. The adipose fin mark was always included in a triple-mark combination.

The number, length, weight and mark of each lot of rainbow trout planted each year varied considerably (Table 1). Trout were actually planted in 1961, but only some of the groups were marked, and only a

few were censused that year. Therefore, these fish were not included in the analysis. Similarly, these strains were also planted in 1967, but were not compared that year because returns were incomplete. Small numbers of other strains were also planted during intervening years and these are not compared either.

Evaluation

The four strains were compared with respect to total harvest in numbers and pounds, and cost per pound in the creel. Their contributions to the fishery was also compared in relation to various fishing methods, and emigration from the reservoir was examined.

Data were collected by a four day per week creel census at the reservoir from 1963 through 1967. (In 1962, the census was conducted on almost a seven day per week basis, as only 11 days were not censused out of a total of 187.) Both weekend days and two weekdays per week were censused. Weekdays were censused on a stratified basis so that each was censused at least twice a month. The basic goals were to estimate total angler hours (effort), and total number and pounds of trout caught. The method involved attaining complete use and catch data for given days of census and directly expanding these data to estimate data for days not censused. The "expansion factor" was the ratio of the number of days (weekend or weekday) in a month to the number of days censused (weekend or weekday). This procedure applied essentially to weekdays as only rarely did we fail to census on a weekend day. Data were expanded separately for weekends and weekdays and the results summarized by month. National holidays were considered as weekend days. We determined that on each census day at least 90%, and on most days, virtually 100% of the total angler catch and effort was recorded. For our analysis, we assumed that 100% of the catch and effort was sampled on all census days.

Data were obtained from each angler on time fished (to the nearest quarter hour) and method of capture. As time permitted, trout were also measured or weighed. Many anglers cleaned their trout before leaving the reservoir, reducing the number that could be weighed.

Anglers who fished in the afterbay or the river below the afterbay were also censused. They seldom fished more than one or two miles below the afterbay, as this portion of the river is accessible only by foot. A road about 4 miles below the afterbay allowed access to the river there. Anglers fishing upstream from that point toward the afterbay did not enter the Beardsley census.

Costs of raising domestic rainbow trout in California hatcheries have been determined (California Dept. of Fish and Game, unpublished). The cost varies from about \$1.45/lb for fingerlings 1.0/oz to \$16.00/lb for fingerlings 200/oz. The cost of raising wild-strain Kamloops was determined by considering not only the actual food and manpower costs but the value of the catchable trout taken out of production as well. For example, it takes about one year to raise the Kamloops to 1.8/oz. During that time domestic strains can be raised to catchable size of about 5.5/lb. Comparative costs for the domestics and Kamloops at this point are \$0.88/lb and \$2.70/lb, respectively. Therefore, for any group of Kamloops and domestics of comparable size we assigned the

TABLE 1

Number, Size and Mark of Each Strain of Rainbow Trout Planted in Beardsley Reservoir, 1961–1967

Date	Species and strain*	Number	No. per ounce	Mark†
April 18–20, 1961	RT-V	25,000	2.5	Ad
April 18–20, 1961	RT-V	25,000	2.5	--
Sept. 15, 1961	RT-W	20,000	9.6	Ad-RV
Sept. 15, 1961	RT-W	30,000	9.6	--
Oct. 19, 1961	RT-K	20,000	12.0	--
Oct. 19, 1961	RT-K	20,000	12.0	LV
Feb. 15, 16, and 19, 1962	RT-K	15,000	3.5	Ad-LV
	RT-K	15,000	3.5	--
Aug. 15, 1962	RT-W	10,000	10.5	RV
Sept. 14, 1962	RT-W	10,000	8.5	RP
Oct. 15, 1962	RT-W	10,000	3.7	LP
Oct. 15, 1962	RT-K	10,000	15.0	RV-LV
April 22, 1963	RT-K	10,000	1.5	RM
April 22, 1963	RT-V	10,000	3.0	Ad-LM
May 13, 1963	RT-K	10,000	1.0	LM
July 26, 1963	RT-S	10,000	6.0	D
July 26, 1963	RT-W	10,000	20.0	D-Ad
Aug. 27, 1963	RT-W	20,000	10.3	D-LV
Sept. 25, 1963	RT-W	10,000	5.0	D-Ad-LV
Sept. 25, 1963	RT-S	10,000	2.5	D-RV
April 16, 1964	RT-V	10,000	2.8	D-LM
April 16, 1964	RT-K	10,000	2.2	Ad-LV-RV
June 18, 1964	RT-S	5,000	9.0	LV-LM
July 31, 1964	RT-S	5,000	4.5	LV-RM
July 31, 1964	RT-W	10,000	18.5	Ad-RV-LM
Aug. 31, 1964	RT-S	5,000	2.8	RV-RM
Aug. 31, 1964	RT-K	10,000	51.5	Ad
October 13, 1964	RT-K	10,000	38.0	Ad-RV
May 5, 1965	RT-K	5,000	3.2	D-Ad-RM
May 24, 1965	RT-K	5,000	2.8	D-Ad-LM
May 24, 1965	RT-S	10,000	30.0	RV
June 15, 1965	RT-K	3,000	1.5	D-Ad-RV
June 15, 1965	RT-S	10,000	16.0	Ad-RM
July 16, 1965	RT-S	10,000	6.2	Ad-LM
July 16, 1965	RT-W	10,000	27.0	LV
July 30, 1965	RT-S	10,000	4.6	Ad-LV-RM
August 25, 1965	RT-S	10,000	2.5	Ad-RV-LV
May 19, 1966	RT-K	16,200	1.4	Ad-LV
June 23, 1966	RT-S	10,000	14.0	LM
July 29, 1966	RT-W	10,000	11.5	D
July 29, 1966	RT-S	10,000	5.0	LV-RM
August 25, 1966	RT-S	10,000	3.9	RM
May 19, 1967	RT-K	5,000	0.8	RV-RM
May 19, 1967	RT-K	5,000	3.8	RV
May 19, 1967	RT-K	5,000	3.8	RV-LM
August 9, 1967	RT-S	10,000	11.3	LV
September 14, 1967	RT-S	10,000	3.8	D-LV

* RT-W = Whitney strain, RT-V = Virginia strain, RT-K = Kamloops strain, RT-S = Shasta strain.
† Ad = adipose, D = dorsal, M = maxillary, V = ventral, P = pectoral, L = left, R = right.

Kamloop a cost three times greater than that of the domestics. To determine the cost per pound in the creel, we divided the total cost to produce a given group of trout by the total pounds of that group harvested.

RESULTS

Percentage Harvest

Kamloops Rainbow

Harvest rates of Kamloops rainbow fingerlings planted in the spring were consistently high (Table 2). Seven groups released in four different years were harvested at rates ranging from about 17 to 33%. When released, these trout were between 9 and 12 months old, and ranged from 3.2 to 1.0 per ounce (3.5 to 5.0 inches FL). The harvest of 32.8% for the single 1966 release was substantially greater than the remainder.

Trout planted in late spring were recaptured at a greater rate than those planted at other times of the year. A single group of Kamloops planted in February 1962 represented the sole winter release of the entire study. The harvest of this group was virtually half that realized from plants made in the spring. Four groups of fish-of-the-year, one released in August and three released in October, were harvested at a uniformly low rate.

Shasta Rainbow

Of the domesticated strains, only the Shasta strain was harvested in significant numbers. However, there was substantial year-to-year variation (Table 3). In contrast with the Kamloops fingerlings, spring releases of Shastas generally gave poor results. Because Shasta eggs usually hatch in early March, they were only available from 16.0 to 9.0 per ounce in June compared with the more successful July and August releases which ranged from 6.2 to 2.5 per ounce. Comparing plants made in the same year, mid-summer releases tended to give better results than those released either earlier or later. Although they are at a larger size when released later in the season, conditions in the reservoir then may be less favorable for survival than earlier in the summer. The most successful Shasta group was harvested at a rate of 21.8%.

Whitney and Virginia Rainbow

Except for a single group, Whitney fingerlings gave uniformly poor results (Table 4). The exception was 10,000 fish at 20.0 per ounce (2.1 inches FL) released in July 1963. Percentage harvests for the remaining nine groups averaged 2.5%. All groups were fish-of-the-year released from late July to mid-October.

The progressive increase in mean size of groups planted during the summer and fall was not accompanied by higher harvest rates. In fact, an inverse relationship between size at release and percentage harvest was indicated. Earlier plants gave decidedly superior results even though the fish doubled their size each month in the hatchery. This again suggests that there is no advantage to be gained by planting

TABLE 2

Harvest of Kamloops Rainbow Fingerlings Planted in Beardsley Reservoir, 1961–1966

Date	Number per ounce at release	Number planted	Number caught	Percentage caught of number planted	Pounds planted	Pounds caught	Pounds caught / Pounds planted	Cost per pound in the creel ($)
February 1962	3.5	15,000	1,467	**9.8**	267.9	843.4	**3.1**	**2.58**
April 1963	1.5	10,000	1,821	**18.2**	416.7	878.0	**2.1**	**2.49**
April 1964	2.2	10,000	2,341	**23.4**	284.1	1,072.0	**3.7**	**1.71**
May 1963	1.0	10,000	2,474	**24.7**	625.0	1,198.6	**1.9**	**2.22**
May 5, 1965	3.2	5,000	833	**16.7**	97.7	360.3	**3.7**	**2.13**
May 24, 1965	2.8	5,000	881	**17.6**	111.6	389.3	**3.5**	**2.10**
May 1966*	1.4	16,200	5,307	**32.8**	723.2	2,254.8	**3.1**	**1.62**
June 1965	1.5	3,000	598	**19.9**	125.0	266.4	**2.1**	**2.46**
August 1964	51.5	10,000	183	**1.8**	12.1	88.1	**7.3**	**4.17**
October 1961	12.0	20,000	1,036	**5.2**	104.2	593.1	**5.7**	**2.67**
October 1962	15.0	10,000	207	**2.1**	41.7	90.9	**2.2**	**7.71**
October 1964	38.0	10,000	247	**2.5**	16.4	130.7	**8.0**	**3.24**
Total or mean		124,200	17,395	**14.02**	2,825.6	8,165.6	**2.88**	**2.93**

* Does not include 3rd-year returns.

TABLE 3

Harvest of Shasta Rainbow Fingerlings Planted in Beardsley Reservoir, 1963–1966

Date	Number per ounce at release	Number planted	Number caught	Percentage caught of number planted	Pounds planted	Pounds caught	Pounds caught / Pounds planted	Cost per pound in the creel ($)
May 1965	30.0	10,000	620	**6.2**	20.8	217.2	**10.4**	**0.75**
June 1964	9.0	5,000	377	**7.5**	34.7	94.4	**2.7**	**1.63**
June 1965	16.0	10,000	973	**9.7**	39.1	360.9	**9.2**	**0.62**
June 1966*	14.0	10,000	671	**6.7**	44.6	237.9	**5.3**	**1.03**
July 1963	6.0	10,000	2,176	**21.8**	104.2	1,054.5	**10.1**	**0.35**
July 1964	4.5	5,000	187	**3.7**	69.4	57.6	**0.8**	**3.70**
July 16, 1965	6.2	10,000	1,554	**15.5**	100.8	566.8	**5.6**	**0.65**
July 30, 1965	4.6	10,000	1,900	**19.0**	135.9	691.3	**5.1**	**0.61**
July 1966*	5.0	10,000	635	**6.4**	125.0	266.6	**2.1**	**1.51**
August 1964	2.8	5,000	295	**5.9**	111.6	101.5	**0.9**	**2.68**
August 1965	2.5	10,000	1,710	**17.1**	250.0	593.8	**2.4**	**0.96**
August 1966*	3.9	10,000	541	**5.4**	160.3	220.2	**1.4**	**2.08**
September 1963	2.5	10,000	1,014	**10.1**	250.0	524.1	**2.1**	**1.09**
Total or mean		115,000	12,653	**11.0**	1,446.4	4,986.8	**3.44**	**1.36**

* Does not include 3rd-year returns.

TABLE 4

Harvest of Whitney Rainbow Fingerlings Planted in Beardsley Reservoir, 1961–1966

Date	Number per ounce at release	Number planted	Number caught	Percentage caught of number planted	Pounds planted	Pounds caught	Pounds caught / Pounds planted	Cost per pound in the creel ($)
July 1963	20.0	10,000	1,084	**10.8**	31.2	568.1	**18.2**	**0.35**
July 1964	18.5	10,000	160	**1.6**	33.8	73.7	**2.2**	**2.81**
July 1965	27.0	10,000	136	**1.4**	23.1	47.2	**2.0**	**3.60**
July 1966*	11.5	10,000	123	**1.2**	54.3	40.8	**0.8**	**6.59**
August 1962	10.5	10,000	407	**4.1**	59.5	113.2	**1.9**	**2.49**
August 1963	10.3	20,000	1,377	**6.9**	121.4	712.2	**5.9**	**0.80**
September 1961	9.6	20,000	943	**4.7**	130.2	464.6	**3.6**	**1.28**
September 1962	8.5	10,000	43	**0.4**	73.5	11.4	**0.2**	**27.85**
September 1963	5.0	10,000	163	**1.6**	77.4	75.4	**1.0**	**5.22**
October 1962	3.7	10,000	40	**0.4**	168.9	8.3	**0.04**	**56.77**
Total or mean		120,000	4,476	**3.7**	773.3	2,114.9	**2.73**	**10.78**

* Does not include 3rd-year returns.

fingerlings later in the summer, even though they may be larger than those planted earlier.

Virginia strain fingerlings were least successful (Table 5), averaging only 4.2%.

Distribution of Total Catch by Year of Recovery

Of the total catch for any given group planted, the greatest number and weight almost always were recovered in the second year; i.e., the second calendar year of life in the reservoir (Table 6). Next highest returns, by both number and weight, were recorded during either the first or third years, depending upon the strain. Relatively few fish of any strain were caught after the third year. Generally, fish released later in the season and/or at a smaller size were recaptured at a lower rate the first year. Releases made in 1966 were not included in this analysis, and fourth-year harvests for 1965 plants were considered zero.

Recoveries of yearling Kamloops planted from February to June were greatest in the second year (Table 6). Kamloops planted in August and October, too small to harvest in the first year, returned in greatest proportion the third year. Only 0.5% by number and 1% by weight represented four-year and later returns from Kamloops yearlings stocked in 1963 and 1964. Compared with Kamloops planted in the spring, relatively fewer Shastas were recaptured the year of release, more the second year, and about the same the third (Table 6). This can be attributed to Shastas being stocked at a smaller size and later in the year. Fourth-year recaptures of Shastas were the lowest of any strain.

Because of their small size at release, relatively few Whitneys were recaptured during their first calendar year in the reservoir (Table 6). Results were more variable than those for the Kamloops and Shastas, but much of this variability was caused by high first-year returns from the July 1964 and August 1962 plants. Ignoring these two, recovery patterns for the remaining seven groups averaged 2.1% by number and 0.4% by weight in the first year and 88.3% by number and 78.1% by weight in the second year. Third- and fourth-year recoveries were highly variable. Proportionately more Whitneys were recaptured during the third and fourth years than either the Kamloops planted from February through June or the Shasta strains.

Harvest of Virginia rainbow was greatest in the first year, decreasing progressively through the fourth year (Table 6). Greatest numbers were harvested in the first year, while the recovery by weight was about equally distributed between the first and second years.

Pounds Harvested

Although the Kamloops were harvested at a greater rate than the Shastas, the latter displayed a higher average ratio of pounds caught to pounds planted (Tables 2 and 3). Even the Whitneys (Table 4) had a ratio of pounds caught to pounds planted nearly equal to that of the Kamloops. The ratio for the Virginias, however, was substantially lower than the others (Table 5). This suggests that the Shastas were able to utilize the "productivity" of the reservoir more efficiently than the Kamloops, since for each pound of both strains planted approximately $\frac{1}{2}$ lb more of Shastas was harvested.

TABLE 5

Harvest of Virginia Rainbow Fingerlings Planted in Beardsley Reservoir, 1963–1964

Date	Number per ounce at release	Number planted	Number caught	Percentage caught of number planted	Pounds planted	Pounds caught	Pounds caught / Pounds planted	Cost per pound in the creel ($)
April 1963	3.0	10,000	218	**2.2**	208.3	96.3	**0.5**	**5.49**
April 1964	2.8	10,000	619	**6.2**	223.2	134.5	**0.6**	**4.05**
Total or mean		20,000	837	**4.2**	431.5	230.8	**0.5**	**4.77**

TABLE 6

Mean Percentage Harvest of Planted Rainbow Trout in Beardsley Reservoir During Four Years of Liberty, 1962–1967

Strain	Mean no./oz. at release	Mean total percent harvest	Year 1		Year 2		Year 3		Year 4+	
			By number	By weight	By number	By weight	By number	By weight	By number	By weight
Kamloops										
Feb.-June	2.2	**18.6**	33.1	15.7	58.7	69.6	7.8	14.0	0.3	0.6
Aug., Oct.	29.1	**2.9**	0.0	0.0	32.6	20.2	57.3	65.6	10.0	14.2
Shasta	8.4	**11.6**	25.4	10.0	69.8	80.0	4.6	9.7	0.1	0.3
Whitney	12.6	**3.5**	7.8	1.8	79.8	72.8	11.3	21.9	1.1	3.5
Virginia	2.9	**4.2**	70.3	42.1	24.9	47.8	3.6	7.7	1.0	2.3

Cost

Costs per pound in the creel for Kamloops yearlings planted from April through June were quite uniform and ranged from $1.62 to $2.49. Costs for the remaining plants were higher and more variable. Costs per pound in the creel were less than $1.00 for six of the 13 groups of Shastas. Overall, these were the lowest of all strains. Costs fluctuated from a low of $0.35 to a high of $3.70 per pound. The cost to put a pound of Whitneys in the creel was extremely variable and tended to be quite high. The cost per pound of Virginias in the creel was $4.77 for the two groups tested.

Contribution to Boat and Shore Angling

The contribution of the Kamloops and domestic strains to the catch of boat and shore anglers was compared from 1964 through 1967 (Table 7). For all but one month of the fishing season during this period the catch per hour of Kamloops rainbow was higher for the boat fishermen than for the shore fishermen, while the catch per hour of the domestic rainbow was greater for boat fishermen only about half of the time. If we can assume that catch per effort was proportional to abundance, it would appear from the above data that Kamloops occupy the open-water areas of the reservoir more than the littoral areas, while the domestic strains were distributed more equally between the littoral and limnetic zones. Unfortunately this is the only information we have relating to the distribution of the rainbow strains in the reservoir; therefore, these inferences are only tentative.

Emigration

Trout can leave reservoirs by ascending tributaries or by descending spillways or turbine intakes. Such emigration may seriously reduce the fishery. Therefore, it is important to know to what degree a particular strain of trout is apt to emigrate.

The only tributary to Beardsley Reservoir large enough to attract emigrating trout is the Middle Fork of the Stanislaus River, which the reservoir impounds. Anglers fishing the river upstream from the reservoir did not normally enter the Beardsley census. The few who did were boat anglers who beached their crafts and walked upstream, usually for only a short distance. Only an occasional marked fish was recorded in the census of these anglers; therefore, it was not possible to estimate the degree of upstream emigration by each of the strains.

Downstream emigration was more evident, however, as anglers fishing the afterbay and the river below entered the census in considerable numbers. Beginning in 1965, all anglers fishing downstream were interviewed. More Kamloops than domestics were caught in the downstream areas than in the reservoir each year from 1965 through 1967 (Table 8). This is somewhat surprising, since considerably more domestic trout were planted than Kamloops. It indicates that Kamloops occurred in the downstream area in greater relative abundance than in the reservoir, and suggests that they emigrated from the reservoir at a greater rate than the domestic strains.

TABLE 7

Boat and Shore Angler Success Rates (Catch per hr.) at Beardsley Reservoir for Planted Kamloops and Domestic Rainbow Trout, 1964–1967

Year	Angler category	Strains	April and/or May	June	July	August	September	October
1964	Boat	Kamloops	0.183	0.072	0.028	0.060	0.152	0.142
		Domestics	0.354	0.150	0.047	0.072	0.128	0.157
	Shore	Kamloops	0.083	0.035	0.021	0.021	0.040	0.178
		Domestics	0.262	0.136	0.105	0.039	0.112	0.388
1965	Boat	Kamloops	0.068	0.038	0.039	0.068	0.152	0.233
		Domestics	0.029	0.024	0.025	0.035	0.058	0.372
	Shore	Kamloops	0.014	0.024	0.003	0.012	0.018	0.040
		Domestics	0.032	0.050	0.010	0.015	0.036	0.185
1966	Boat	Kamloops	0.122	0.087	0.149	0.153	0.485	0.298
		Domestics	0.402	0.127	0.089	0.061	0.079	0.212
	Shore	Kamloops	0.068	0.011	0.008	0.010	0.043	0.068
		Domestics	0.275	0.119	0.097	0.049	0.082	0.304
1967	Boat	Kamloops	0.213	0.058	0.089	0.067	0.261	0.264
		Domestics	0.127	0.045	0.031	0.028	0.019	0.015
	Shore	Kamloops	0.034	0.036	0.086	0.036	0.050	0.050
		Domestics	0.074	0.059	0.087	0.020	0.034	0.043

TABLE 8

Catch Per Hour of Four Strains of Rainbow Trout in Beardsley Reservoir and Downstream From Beardsley Reservoir, 1965–1967

Strain	1965		1966		1967	
	Reservoir	Down-stream	Reservoir	Down-stream	Reservoir	Down-stream
Kamloops	.071	.036	.146	.014	.135	.149
Shasta	.044	.009	.209	.007	.053	.022
Whitney	.008	.006	.006	.001	.005	.003
Virginia	.003	.005	.000	.001	.000	.000
C/h Kamloops / C/h domestics	1.268	1.800	.679	1.556	2.328	5.960

Most downstream emigrants apparently passed over the spillway. Each year since 1962 water has discharged over the spillway in varying amounts and for varying lengths of time, usually during the spring with snowmelt runoff. Coincident with the onset of spill, marked trout caught in the afterbay had extensive bruises and badly frayed fins, apparently as a result of cascading down the concrete spillway. Furthermore, in 1965 and 1967, years of unusually heavy runoff, the catch per hour of marked trout in the downstream areas was substantially greater than in 1966 (Table 8), a year of below normal runoff.

We do not know whether any trout emigrated through the turbine intakes or what mortality they may have suffered if they did. The depth of the intake is so great, however, it is doubtful that trout were lost via this route.

MANAGEMENT IMPLICATIONS

Theoretically, planted fingerling trout should be able to serve as a supplement to recruitment in reservoirs where natural reproduction is insufficient to sustain a fishery for wild trout. We have seen, however, that the harvest of fingerling rainbow trout planted in Beardsley Reservoir can be influenced greatly by the strain planted. A small literature exists which suggests there are indeed important differences in the survival and growth in nature between wild and domestic trout. These differences are not completely clear, however. Green (1951) found little difference in the average harvest rates of wild and domestic fingerling eastern brook trout (*Salvelinus fontinalis*) planted in a natural pond. He noted that the "wild" strain may have been influenced in the past by domestic genes. Flick and Webster (1964), however, showed that wild strains of brook trout had higher survival rates than domestic strains in two Adirondack ponds. When Mason, Brynildson and Degurse (1967) tested wild and domestic brook trout and their hybrids in five Wisconsin streams, they found that the wild strain had the highest summer survival, while it had the highest overwinter survival in only one stream—where there was permanent ice cover.

Smith (1957) took eggs from a wild strain of rainbow trout and raised them in a hatchery to the fry stage. He then transferred one

group to a natural pond and raised another group in the hatchery. Both groups were planted in Corbett Lake, British Columbia, as fingerlings. He found no difference in either the survival or growth rates of the two groups. Repeating the experiment with another year class, he again found no difference in the survival rates, but the pond-raised fish had a higher growth rate than the hatchery-raised fish. Nielson, Reimers and Kennedy (1957) planted catchable domestic rainbow trout in Convict Creek, California, and found no difference between their survival and that of comparable size wild brown trout, except in unusually severe or protracted winters when the survival of domestic rainbow trout was lower.

These studies, although inconclusive, suggest that while survival of wild and domestic trout may be comparable in many situations, domestic trout do more poorly than wild trout in environments that are particularly rigorous. Although the size of the non-game fish populations in Beardsley were not known, they appeared to be quite large. Thus, competition and predation by non-game fish may have exacted a greater toll of planted domestic trout than of Kamloops, leading to the differences we observed in their harvest rates.

The harvest of Whitney and Virginia strain rainbow was so markedly low, we are led to conclude that it would be best to avoid their use in coldwater reservoirs. The most successful strains of those tested, using the criteria we employed, were the Kamloops and Shastas. Kamloops were harvested in greatest numbers when planted in April and May at around 1.0–3.2 per ounce (Table 3). If we compared only these most successful groups (Table 9) we find that Kamloops were harvested at a significantly greater rate than the Shastas, although the latter had a higher ratio of pounds caught to pounds planted and a lower cost per pound in the creel.

There appears to be certain characteristics possessed by the Kamloops, however, that make them less than ideally suited to coldwater reservoirs. These include thair apparently greater tendency to emigrate from the reservoir and their predilection for open water areas of the reservoir. The latter decreases their availability to shore anglers. These are relatively minor problems, however, and we feel they will prove superior to domestic strains in a majority of situations.

TABLE 9

Mean Values of the Best Groups of Kamloops and Shasta Rainbow Trout Tested in Beardsley Reservoir, and Results of *T*-Test

	Percent caught	Pounds caught / pounds planted	Cost per pound in the creel
Kamloops (n = 6)_____	22.23	3.00	$2.04
Shasta (n = 8)_____	11.85	3.55	$1.57
t	**2.91***	**0.46**	**$1.10**

* Significant at p = .05.

Hatchery Problems

The wild characteristics that make Kamloops a superior strain in reservoirs, apparently makes them totally unsuited to the operations of California's trout hatcheries, geared for the mass production of catchable trout. They are slow growing, display a wide variation in size and require greater care and handling. These are characteristics which make them more costly, and which have been bred out of the domestic strains of rainbow trout. These problems, we believe, could be greatly reduced if a hatchery were designed to raise wild fish. The use of automatic feeders, graders and other equipment would lower handling costs and increase the growth rate in the hatchery, leading to lower overall production costs.

If Kamloops are not used, the best alternate would appear to be Shastas. Their performance could be improved, we believe, if they could be planted earlier in the summer or in the spring at a larger size than they are presently available. Moving the Shasta broodstock spawning time back to November and December may produce this desired change.

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FISHES ASSOCIATED WITH DRIFTING KELP, *MACROCYSTIS PYRIFERA*, OFF THE COAST OF SOUTHERN CALIFORNIA AND NORTHERN BAJA CALIFORNIA[1]

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Fifty collections of fishes associated with drift-kelp were made offshore of southern California and Baja California, Mexico, with a miniature purse seine. Twenty-one species and 15 families of fishes were represented. Juvenile stages predominated, adults of only seven of the species were captured. The body coloration of the species was related to the distance they usually maintained from the drifting kelp plant. Darker colored species remained closer to the kelp than did silvery ones. Most species were probably recruited in the pelagic environment. A laboratory experiment on the effectiveness of kelp in reducing predation indicated that fishes associated with kelp, were pursued less often, for shorter periods, and captured less frequently by a predator.

INTRODUCTION

The association of fishes with drifting material in the pelagic environment has been widely recorded (Hunter and Mitchell, 1967, 1968; Hirosaki, 1963a, 1963b, 1964, 1965; Senta, 1962, 1965) but no description of the fish fauna associated with drifting materials exists for southern California. Southern California sport and commercial fishermen fish near drifting kelp plants for yellowtail, *Seriola dorsalis*, albacore, *Thunnus alalunga*, (Fitch, 1960), and occasionally dolphin fish, *Coryphaena hippurus*. Other California species that have been observed associated with flotsam are: opaleye, *Girella nigricans*, (Baxter, 1966); halfmoons, *Medialuna californiensis*, (Follett, Gotshall, and Smith, 1960); giant kelpfish, *Heterostichus rostratus*, (Hubbs, 1920); and the rockfishes, *Sebastes nigrocinctus* and *S. caurinus*, (Hitz, 1961).

The objective of this study was to describe the fish fauna that accompanies drifting seaweed in offshore waters of southern California. During 1964–68, we made diving observations and took 50 collections with a miniature purse seine of fishes aggregating beneath drifting seaweed (Hunter, Aasted, and Mitchell, 1966). Most of the collections were made to acquire live laboratory specimens for other studies; therefore, no regular sampling program was established. Collections were made more frequently in the summer than in the winter, and

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sampling was concentrated in two very productive areas, northwest of Los Coronados Islands, Baja California, Mexico, and near Santa Catalina Island, California (Figure 1). In some cases estimates of numbers and size of individuals were recorded instead of actual measurements because the fish were later maintained for extended periods in large tanks in the laboratory.

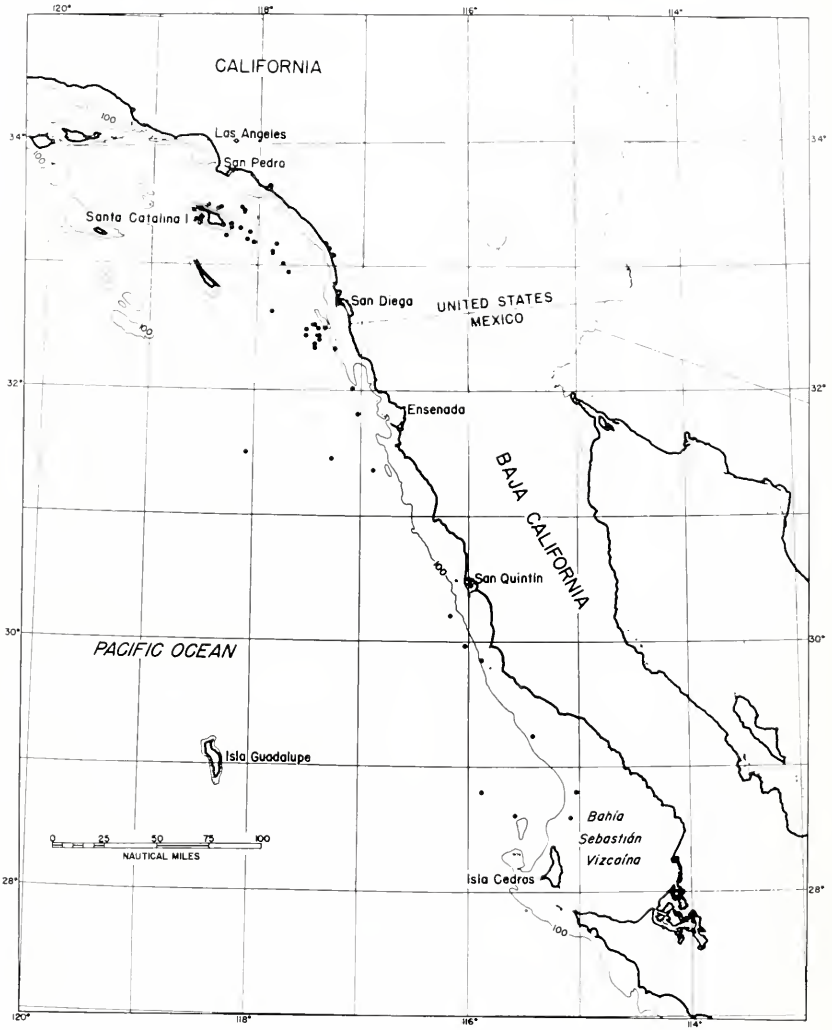

FIGURE 1—Locations of collections made on drifting kelp off the coasts of southern California and Baja California, Mexico between 1964 and 1968.

Drifting clumps of seaweed were predominantly giant kelp, *Macrocystis pyrifera*, but sometimes other common subtidal brown algae, *Pelagophycus porra, Pterygophora californica, Cystoscira osmundacea,*

and *Egregia laevigata* were intertwined with the giant kelp (Figure 2). Although we frequently examined drifting species other than giant kelp, none were observed to have an associated fish fauna and we did not see any fish near other flotsam such as wooden crates, planks, and logs as was the case in the eastern tropical Pacific where almost any type of floating debris had an associated fish fauna (Hunter and Mitchell, 1967, 1968).

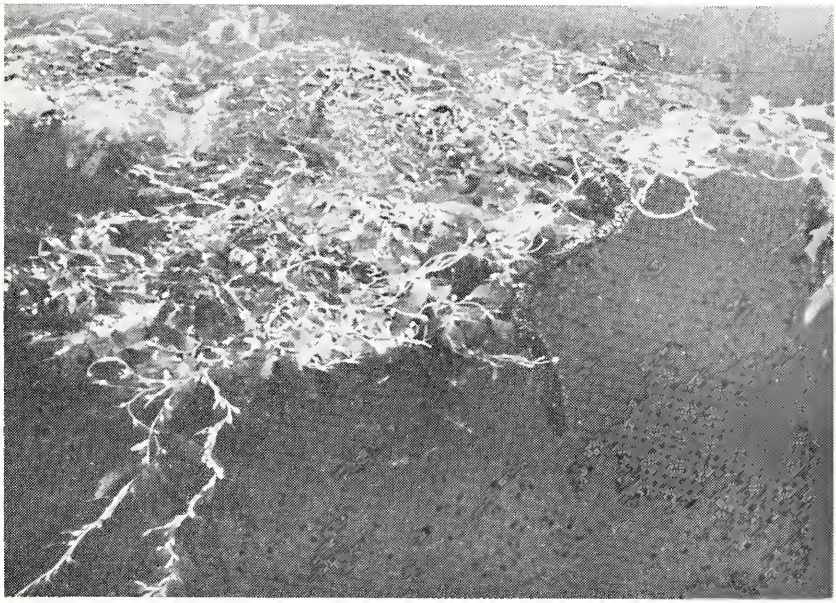

FIGURE 2—A typical drifting kelp mat near Santa Catalina Island. Adult halfmoon, *Medialuna californiensis*, can be seen in the lower center.

Many of the giant kelp plants we sampled exhibit thick stipes and large round pneumatocysts of the type commonly found in kelp beds around the more northern Channel Islands (Wheeler J. North, California Technical Institution, pers. comm.). Thus, much of the kelp we sampled probably had drifted in a southerly direction. The kelp ranged in wet weight from about 1.4 kg, for a portion of one giant kelp plant to over 450 kg for clumps of many intertwined complete plants. Some clumps of drifting kelp larger than 450 kg with an associated fish fauna were sighted but were too large to surround with the miniature purse seine. Underwater observations of these larger drifting clumps indicated that the fish fauna was similar to that of smaller kelp clumps.

RESULTS

Twenty-one species representing 15 families of fishes were collected (Table 1). Most of the fish were juveniles; only adults of seven species were collected. Halfmoons and splitnose rockfish, *Sebastes diploproa*, were the most frequently occurring and most abundant species. Each of these two species comprised about 80% of the total individuals cap-

TABLE 1

Number of Individuals, Frequency, Length, Life Stage, and Months of Occurrence of Fishes Collected Beneath Drifting Kelp

Common names	Species	Total captured	Frequency[1]	Range of standard length	Life stage[2]	Occurrence
		number		*mm*		*months*
Kelp pipefish	*Syngnathus californiensis*	41	13	153–292	A	June, July, Sept., Dec., Jan.
Kelp bass	*Paralabrax clathratus*	8	4	31–80	J	Sept., Dec., Jan.
Yellowtail	*Seriola dorsalis*	7	1	35[3]	JA	Aug.
Jack mackerel	*Trachurus symmetricus*	753[4]	19	16–500	JA	June, July, Sept., Dec., Jan.
Pacific mackerel	*Scomber japonicus*	1	1	65	J	Sept.
Kelp perch	*Brachyistius frenatus*	1	1	49	J	July
Blacksmith	*Chromis punctipinnis*	179	8	15–34	J	June, Sept., Dec., Jan.
Opaleye	*Girella nigricans*	15	5	173–279	JA	June, Dec., Jan.
Halfmoon	*Medialuna californiensis*	3,751[4]	37	23–292	JA	June, July, Sept., Dec., Jan.
Bocaccio	*Sebastes paucispinis*	25	7	31–76	J	June, Jan.
Olive rockfish	*Sebastes serranoides*	1	1	44	J	June
Splitnose rockfish	*Sebastes diploproa*	2,339[4]	32	17–49	J	June, July, Sept., Dec., Jan.
Flag rockfish	*Sebastes rubrivinctus*	149[4]	9	15–38	J	Sept., Dec., Jan.
Treefish	*Sebastes serriceps*	97	15	17–49	J	June, July
Rockfish	*Sebastes* sp.	4[5]	3	14–34	J	June, Sept.
Sablefish	*Anoplopoma fimbria*	650	15	66–149	J	June, July
Cabezon	*Scorpaenichthys marmoratus*	3	1	70[3]	J	June
Giant kelpfish	*Heterostichus rostratus*	3	2	49–61	J	June, July
Bay blenny	*Hypsoblennius gentilis*	4	2	34–60	JA	Dec.
Clingfish	*Gobiesox eugrammus*	1	1	15.5	J	June
Mola	*Mola mola*	1	1	400	A	June

[1] Total number of collections in which species occurred.
[2] J represents juveniles, A adults.
[3] Standard length estimated.
[4] Includes some estimates of numbers. Range of standard length from individuals actually measured.
[5] No specific identification made.

tured. Both species were taken throughout the year. Halfmoon dominated the community in terms of mass since large juvenile and adult halfmoon were frequently taken whereas all the splitnose rockfish were small juveniles. Halfmoon may breed while associated with drifting kelp since both male and female specimens collected in June 1964 were running ripe.

Other abundant species included kelp pipefish, *Syngnathus californiensis,* jack mackerel, *Trachurus symmetricus,* blacksmith, *Chromis punctipinnis*, flag rockfish, *Sebastes rubrivinctus* and sablefish, *Anoplopoma fimbria*. Sablefish was taken only during the summer whereas the rest were taken in winter and summer. With the exception of kelp pipefish, adult stages in the above fish species were uncommon or never taken.

Many of the species collected inhabit kelp beds along the coast as adults and/or juveniles; others, for example, splitnose rockfish, flag rockfish, and sablefish live in deep water as adults and are pelagic as juveniles. All collected species have pelagic larvae and therefore the juveniles would be available for recruitment in the pelagic environment. We believe that most of the species did not form their association when the kelp was attached, but rather they were recruited in the pelagic environment. The kelp we saw drifting within a few miles of the coast had few or no associated fish. In the tropics (Hunter and Mitchell, 1967, 1968), we collected fish fauna beneath objects moored offshore almost identical to that beneath naturally occurring flotsam. It is possible that a few species which maintain contact with the kelp plant e.g. giant kelpfish and the clingfish, *Gobiesox eugrammus*, may drift offshore with the kelp plant.

Fish will associate with the same floating object for as long as 30 or more days (Hunter and Mitchell, 1968); consequently, fish may be displaced beyond their normal range while accompanying drifting materials. Juvenile sablefish were collected in June and July of 1964 as far south as lat 28°48′ N, long 115°53′ W, almost 130 nautical miles south of their reported southern range (Roedel, 1953).

Halfmoon in groups of two or more individuals frequently fed on chains of pelagic tunicates, *Salpa* sp., (Figure 3) as well as on small pieces of kelp and encrusting organisms which drifted down from the kelp canopy. Other than the pelagic tunicates, halfmoon and opaleye consumed food items similar to those reported for their neritic habitats (Quast, 1968; Follette, Gotshall, and Smith, 1960). The jack mackerel schools we observed beneath kelp frequently fed on items that drifted past the kelp mat. The median frequency of feeding for individuals in a jack mackerel school was 14 snaps/min over about a 4-hr period. The stomach contents of one individual from the school contained 1,454 food items of which 88% were copepods of four genera. Analysis by Conway (1967) of the stomach contents of 100 sablefish in our collections showed that major food items were copepods, euphausiids, and larvacea. These observations suggest kelp association probably has little effect on the diet of most fishes.

When a predator appeared near drifting kelp, the associated fish fauna swam toward the kelp and concentrated just beneath it or within the interstices of the floating seaweed. Most of the time the fish were

more dispersed. They were distributed vertically from within or near the kelp canopy to the limit of visibility (7 to 10 m). Different species occupied different positions in this range and generally the position occupied was correlated with the size and body coloration of the species.

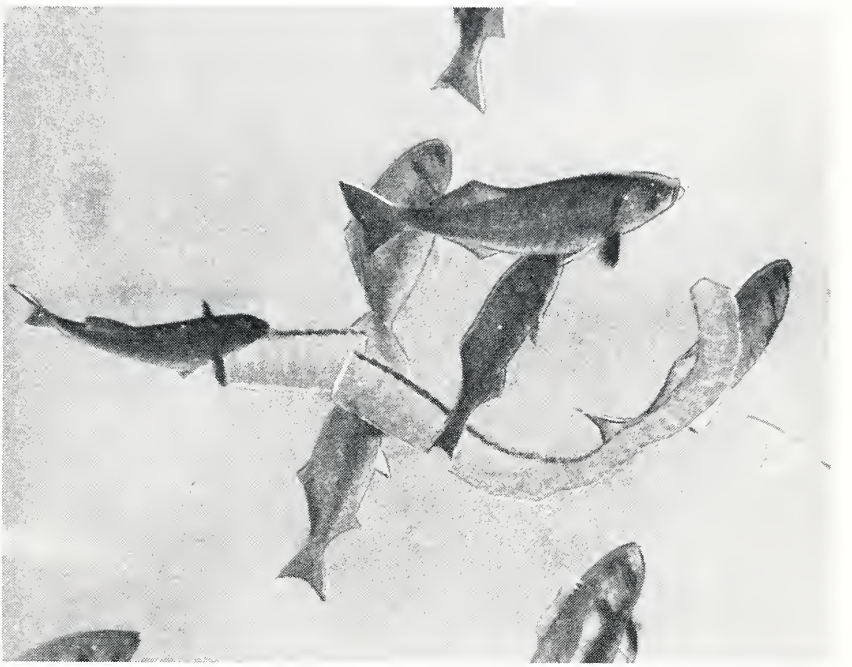

FIGURE 3—An aggregation of halfmoon, *Medialuna californiensis*, feeding on a chain of pelagic tunicates, *Salpa* sp.

The distribution of the fishes fell into three overlapping zones. Zone I fishes remained within a few centimeters of the kelp or within the canopy. These included all the species of rockfish, giant kelpfish, juvenile opaleye, clingfish, kelp pipefish, kelp bass, *Paralabrax clathratus*, kelp perch, *Brachyistius frenatus*, cabezon, *Scorpaenichthys marmoratus*, and bay blenny, *Hypsoblennius gentilis* (Figure 4). These fishes, with the exception of opaleye, were dark brown, orange brown, or had a dark barred pattern. They remained near the seaweed virtually all the time and did not stray from it horizontally or vertically. Zone II fishes remained from .75 m to 8 m from the kelp canopy. Fish in this zone were larger than the ones in Zone I (see Table 1 for size ranges of species) and made the greatest contribution enmass to the typical community. Species occupying this zone included adult and juvenile halfmoon, juvenile yellowtail, sablefish, jack mackerel, and blacksmith (Figure 5). Among these species jack mackerel ranged the farthest from the kelp and occasionally were beyond visual range. Halfmoon and opaleye remained closer to the kelp and nearly always were in view. Species in this zone had pelagic coloration, dark above, silvery below, except for blacksmith which occupied a position somewhat inter-

FIGURE 4—Occupants of Zone I juvenile splitnose rockfish, *Sebastes diploproa*. Portions of kelp canopy visible at top.

mediate in range between Zones I and II. Zone III fishes only occasionally came within 8 m of the seaweed. They were large fish of pelagic coloration including jack mackerel, 20 cm or larger, adult yellowtail, and mola, *Mola mola*. These larger fish appeared within visual range only intermittently.

The most consistent hypothesis for the association of fishes with drifting materials is that the materials provide protection from predation (Breder, 1946; Gooding and Magnuson, 1967). We conducted laboratory experiments to test the effectiveness of floating kelp in reducing predation. Splitnose rockfish (Zone I) 53 to 128 mm TL and opaleye (Zone I) 44 to 54 mm TL were used as prey and were tested in groups of eight fish each. Prey were introduced remotely into the center of a plastic swimming pool (3.7 m diameter) which contained a single predator, ocean whitefish, *Caulolatilus princeps* 500 to 570 mm TL. A small bucket containing eight prey was tripped so that the prey swam out in the center of the tank at the water surface. Records were kept of the frequency and duration of the pursuits of the prey by the predator and the number of fish captured in 50 min. Five groups of eight splitnose rockfish and two groups of eight opaleye were tested in the pool

FIGURE 5—Occupants of Zone II a school of juvenile jack mackerel, *Trachurus symmetricus*, passing beneath a drifting kelp mat. A portion of the kelp canopy can be seen in upper right.

without kelp and the same number of groups of each species were tested when a portion of a kelp plant (550 cm^2 in area) was tethered at the surface in the center of the pool.

Prey were pursued more often, for longer periods, and captured more frequently when kelp was absent than when it was present (Table 2). Only 28 pursuits were recorded for all groups of splitnose rockfish when kelp was present, but 56 were recorded when it was absent. Using opaleye as prey, only two pursuits were recorded when kelp was present and 30 when it was absent. In both species, the frequency and duration of the pursuits and the frequency of capture were significantly lower when kelp was present ($P = 0.01$). Probably pursuits were shorter when kelp was present because the predator lost sight of the prey when it entered or swam near the canopy. Thus, the absence of a kelp cover resulted not only in prey being captured more frequently but in the expenditure of more energy by those fish avoiding capture.

In the field we saw large predators, California sea lions, *Zalophus californianus*, and adult yellowtail feed on the larger fish occupying Zone II. In addition, three of the species that occupy this zone, sablefish, jack mackerel, and halfmoon often had body lacerations presumably caused by predators. For example, 24 of 59 jack mackerel in a single collection had lacerations. On the other hand, no evidence existed for fish feeding on the smaller juveniles that occupy Zone I. The small fishes probably would be consumed rather than injured if attacked. Nevertheless the evidence indicates that the habit of moving within the kelp canopy and the body coloration of the fish which live in Zone I provides them with considerable protection from predation. For the

TABLE 2

Frequency and Duration of Pursuits and Number of Splitnose Rockfish and Opaleye Captured by an Ocean Whitefish With and Without Kelp *

Species	Kelp present			Kelp absent		
	Pursuits		Number captured	Pursuits		Number captured
	Frequency	Mean duration sec		Frequency	Mean duration sec	
Splitnose rockfish	12	7.4	3	17	11.0	3
	8	11.5	2	14	17.8	3
	3	5.7	1	11	5.5	5
	3	2.7	0	9	21.7	5
	2	12.5	0	5	8.0	0
Opaleye	1	25.0	0	18	11.6	1
	1	3.0	0	12	14.1	1

* Splitnose rockfish and opaleye tested in groups of eight fish for 50 minutes.

other fishes, kelp canopies probably do not provide the same degree of protection but may reduce predation to some extent.

ACKNOWLEDGMENTS

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THE REPRODUCTIVE CYCLE, GONADAL HISTOLOGY, AND GAMETOGENESIS OF THE RED ABALONE, *HALIOTIS RUFESCENS* (SWAINSON)[1]

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Ten subtidal specimens of *Haliotis rufescens* were collected monthly for 13 months near Fort Bragg, California. Gonadal histology and cytology are described. Apparently mature gametes were observed in all specimens. Necrosis of oocytes occurred in all monthly samples. No significant rank correlation existed between gonad index and gonad bulk index. No significant variation in gonad index between monthly samples occurred, which indicates that the gonad index is of no value for monitoring the reproductive cycle of red abalone. The lack of seasonal variation in gonad indices is correlated with the presence of apparently mature gametes in all specimens collected. Possible spawning stimuli are discussed.

INTRODUCTION

The red abalone is an important food species along the California coast. It ranges from Sunset Bay, Oregon, to Turtle Bay, Baja California, and inhabits rocky areas from the intertidal zone to depths of over 500 ft (Cox, 1962).

The objectives of this study were to describe the reproductive cycle, gonadal histology, and gametogenesis of red abalones found near Fort Bragg, California (lat 39°26′N, long 123°48′W).

Detailed knowledge of the reproductive cycle of red abalone is essential for proper management. From early observations, it was believed that spawning occurred only during late winter and early spring (Heath, 1925; Bonnot, 1930; Croker, 1931). Cox (1962) believed that spawning is most frequent during late spring and early summer. Boolootian, Farmanfarmaian, and Giese (1962) concluded from smears and gonadal indices that red abalone spawn throughout the year at Pacific Grove, California. Furthermore, they noted that newly settled abalone were found on the holdfast of *Macrocystis* at all times of the year near La Jolla, California.

According to Cox (1962), the spawning season for the different abalone species occurring in California may vary according to geographical location. In South Africa, Newman (1967) found variations in the reproductive cycle of *H. midae* at stations less than 50 miles apart. Webber and Giese (1969) found different spawning times in populations of the black abalone, *H. cracherodii*, that were only 7 miles apart.

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Raven (1966) reviewed the cytology, cytochemistry, and vitellogenesis of molluscan oogenesis. More recently, with the electron microscope, Bolognari (1961a) illustrated two different methods of yolk formation in gastropods. Tomita (1967) reported on the development of eggs in *Haliotis discus hannai* and classified egg development into a number of stages on the basis of the most prominent feature of the cell in a particular stage.

MATERIALS AND METHODS

From March 1968 through March 1969, ten subtidal red abalone specimens were collected monthly near Fort Bragg, California, either with scuba or by free diving. The depths from which abalone were taken ranged to 50 ft.

The shell of each specimen was removed and measured lengthwise in millimeters. The sex was recorded. The gonad was sampled in two areas, near the tip and near the midportion. The latter area was determined by finding the tangent of the gonadal-cone parallel to the longitudinal axis of the animal as the cone lay around the columellar muscle (Figure 1). The samples were fixed in a mixture of formalin, acetic acid, and ethyl alcohol. Portions of each sample were dehydrated in isopropyl alcohol, embedded in paraffin, sectioned at 7 microns, and stained with Ehrlich's hematoxylin and eosin.

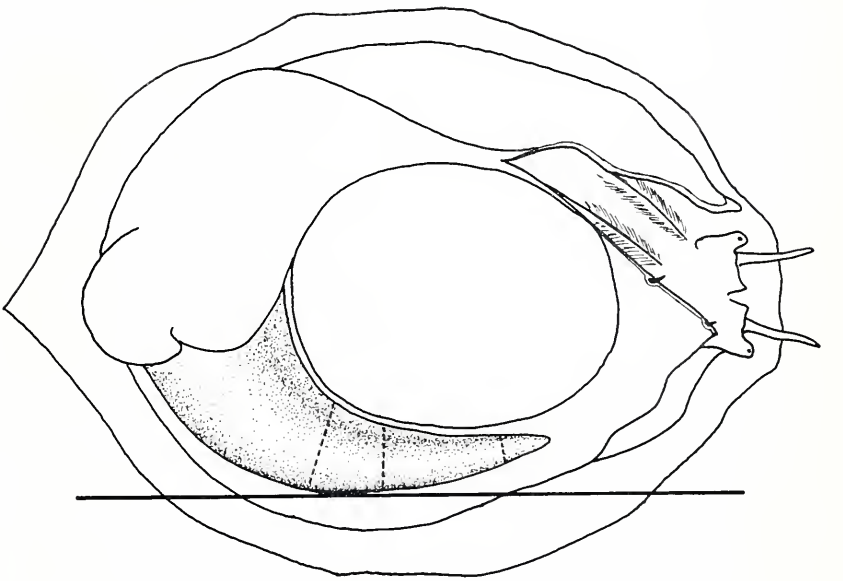

FIGURE 1—*Haliotis rufescens* with shell removed, showing conical appendage (stippled) and sampled areas of the appendage (broken lines). Midportion determined by finding tangent of the cone parallel to the longitudinal axis as shown by heavy line.

The gonad bulk index (Newman, 1967) and the gonad index (Boolootian, et al. 1962) were determined for each specimen from the sam-

ple taken at the midportion of the cone. The indices were calculated as follows:

$$\text{Gonad Bulk Index} = \frac{\text{area of gonad in the section}}{\text{total area of the section}} \cdot 100$$

$$\text{Gonad Index} = \frac{\text{area of gonad in the section}}{\text{shell length}} \cdot 100$$

Tracings of the cross-sectional perimeters of the gonad and digestive gland were made on clear plastic, then their areas were measured by placing the tracings on a Keuffel & Esser 10 × 10 to 1 cm graph sheet.

To test physiologically for the presence of muscular tissue in the gonad, a light was reflected onto a wall from a small piece of foil placed on the exterior of an excised conical appendage. Electrical shocks of 15 volts at a frequency of 2 per second were applied to the gonad. Any movement caused by muscular contraction would be amplified by the distance between the foil and the wall, and could be detected by movement of reflected light.

RESULTS AND DISCUSSION

The Sex Ratio and the Gonadal Indices

In this study, 153 specimens (81 males and 72 females) were used for making the various determinations. The hypothesis that the sex ratio is one to one was tested by using the Chi-square test for goodness of fit. The calculated Chi-square value was 0.529 (Chi-square p. 05, ld.f. = 3.841). The hypothesis was accepted.

To determine whether the gonad bulk index is correlated with the gonad index in our samples, the hypothesis that the two indices are independent was tested using the Spearman rank correlation method (Lewis, 1966). A Spearman rank correlation coefficient of 0.1953 was calculated (r [p.05 N = 60] = 0.250). The hypothesis was accepted. The two indices do not correlate because the total areas of the sections are highly variable for a given shell length.

Boolootian, *et al* (1962) found that monthly samples of gonad indices of black abalones showed seasonal variation in the Pacific Grove area; however, the gonad indices of monthly samples of red abalones showed no seasonal variation. They concluded that the red abalone breeds throughout the year. The monthly ranges of gonad indices of our samples overlapped extensively (Figure 2). A relative cumulative frequency curve of all the gonadal indices was generated on normal probability paper. The points almost fit a straight line and thus we assumed that the gonadal indices are approximately normally distributed. The hypothesis that no monthly variations of gonad indices occurred within the samples was tested using the analysis of variance. An F value of 0.4897 was calculated (F [p.05n_1 = 10, n_2 = 99] = 1.90). The hypothesis was accepted, which indicates to us that red abalone is a potential spawner throughout the year around Fort Bragg, California. It also shows that the gonad index is not a useful criterion for monitoring the red abalone's reproductive cycle.

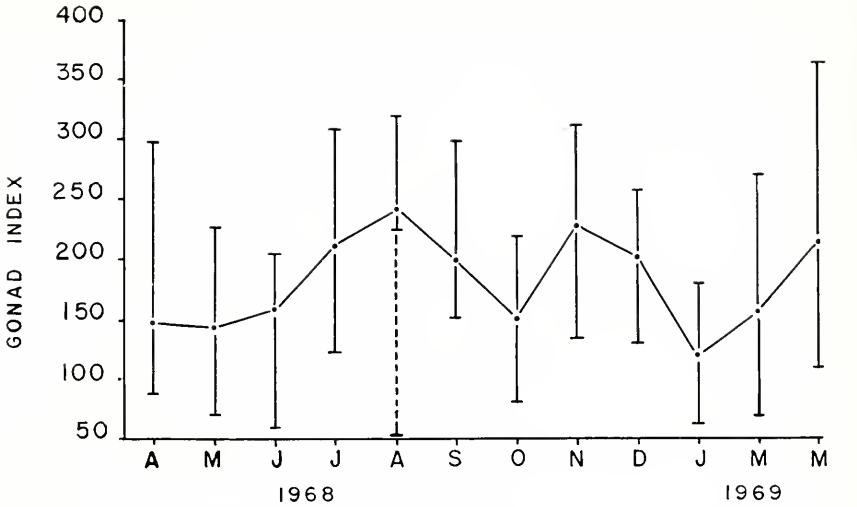

FIGURE 2—Gonad indices for *H. rufescens* for period April, 1968 through March, 1969. Dots are mean values and the vertical line for August, 1968 represents the extension of range to include a single spawned male that had a low gonad index.

According to Ropes (1968) and Webber and Giese (1969), histological sections give a more detailed account of gametogenic events. With this in mind, we studied gametogenesis and histology of the gonad.

The Outer Gonadal Wall

The outer gonadal wall is similar in both sexes. It consists of an epidermis which is a simple, glandular columnar epithelium. The epidermis is covered by a thin cuticle. A muscular wall occurs beneath the epidermis (Figure 3A). This subepidermal wall in *H. lamellosa* (Bolognari, 1953), *H. tuberculata* (Crofts, 1929), and *H. midae* (Newman, 1967) has been described as consisting of only connective tissue. In addition, Newman (1967) states that the tissue is non-contractile. But in the red abalone, fibers that contain elongated nuclei and resemble muscle cells were found along with some connective tissue in the gonadal wall. Electric shock induced contraction of excised conical appendages which corroborates our histological evidence that muscular tissue is present. Contraction of the muscular wall may aid in the release of gametes.

The Testis

Branching tubes of connective tissue project inward from the outer wall of the testis and some extend all the way to the inner testicular wall. The tubes are surrounded by a cuboidal germinal epithelium. Blood sinuses traverse the tubes and are often connected to branches of the hepato-genital blood vessels that run through the proximal portion of the lumen (Figures 3B, 3C, and 3D). The hepato-genital vessels issue through and run paralled to the inner testicular wall. Their outer wall lacks germinal epithelium.

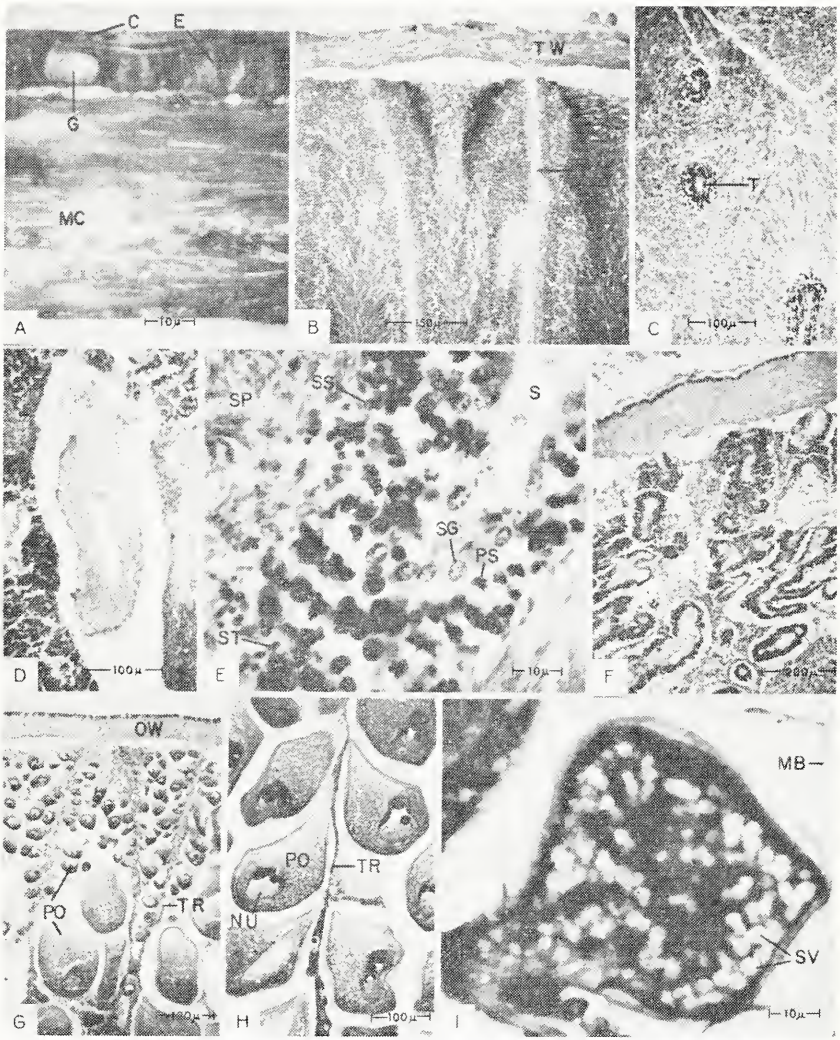

FIGURE 3—A—Outer testicular wall of *H. rufescens*. C = outer cuticle, E = simple glandular columnar epithelium, G = unicellular gland, MC = muscle connective tissue layer. B—Cross section of testis. TW = outer testicular wall, T = tubule of connective tissue. C—Frontal section of testis. T = tubule of connective tissue. D—Hepatogenital blood vessel in testicular lumen. E—Spermatogenesis. SG = spermatogonium, PS = primary spermatocyte, SS = secondary spermatocyte, ST = spermatid, SP = spermatozoa, S = sinus within connective tissue tubule. F—Spawned testis. G—Cross section of ovary; OW—outer averian wall, TR = trabecula, PO = primary oocytes. H—Large, stalked primary oocytes oriented toward digestive gland. TR = trabecula, PO = primary oocyte, NU—nucleus. I—Primary oocyte with membrane sloughed away. MB = membrane, SV = spherical vacuoles.

Spermatogonia are produced by the germinal epithelium. Spermatogonia have nuclei 5 to 7 μ in diameter. Chromomeres of condensed heterochromatin are apparent along with chromonemic strands. The

strands may form a reticulum. The chromatin condenses and becomes appressed against the inner side of the nuclear envelope and forms a synizetic knot or bouquet. The later stages of the first meiotic division were not observed. Our inability to observe later stages of prophase I indicates to us that these stages are of short duration. Nuclei of the primary spermatocytes average 3 to 5 μ in diameter. The nuclei of spherical secondary spermatocytes average about 3 μ across (Figure 3E). Condensed chromatin is frequently visible in the secondary spermatocytes but not in the spermatids.

Spermiogenesis follows and is characterized initially by the formation of an eosinophilic acrosome that undergoes rapid condensation and secondarily by elongation of the nucleus. The mature spermatozoon has a head about 6 μ long and 1 to 1.5 μ wide. The head consists of an anterior eosinophilic acrosome followed by a short clear space; both occupy the first 2.5 μ. A nucleus about 3.5 μ long follows (Figure 4). According to Fretter and Graham (1964), spherical masses of mitochondria lie at or around the posterior end of the head of spermatozoan of archaeogastropods. A short eosinophilic mass, possibly consisting of mitochondria, occurs at the posterior end of the head of spermatozoa of red abalone. A flagellum is barely discernible at 1,000×. Spermatogenesis and the presence of spermatozoa were observed in the males of each monthly sample. Only one male was spawned out (Figure 3F). The shell of this specimen was severely infested with *Cliona*, a boring sponge, thus the condition was possibly a manifestation of pathology.

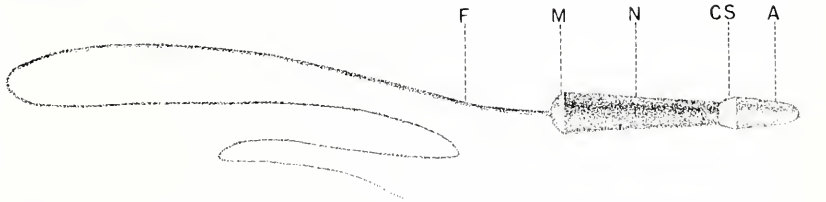

FIGURE 4—Spermatozoon from *H. rufescens*. A = acrosome, CS = clear space, N = nucleus, M = eosinophilic mass that may be mitochondria, F = flagellum.

The Ovary

The red abalone ovary is similar to the descriptions given by Crofts (1929) for *H. tuberculata* and by Newman (1967) for *H. midae*.

Polygonally arranged trabeculae composed of connective tissue and possibly of some muscle fibers, project from the outer ovarian wall toward the digestive gland. Some trabeculae attach to the inner ovarian wall and may serve as supports. Others end freely in the lumen.

Branches of the hepato-genital vessels occur in the inner ovarian wall. Blood sinuses are seldomly apparent within the trabeculae and are probably compressed by the eggs. Small sinuses containing amoebocytes are found in the most distal portions of the trabeculae and in the outer ovarian wall.

A germinal epithelium lines the inside of the ovary. Initially, the epithelium is squamous and subsequently it becomes cuboidal. The areas of apparent transformation were observed most frequently in the

distal portion of the trabeculae and were characterized by clusters of transforming cells (Figure 3G). The cuboidal cells are oogonia, and as they enlarge into primary oocytes they move away from the germinal epithelium and toward the digestive gland, but remain attached by a stalk and appear teardrop shaped (Figure 3H). In addition, isolated epithelial cells become oogonia, commonly on the proximal portions of the trabeculae. The cytoplasm of the oocytes becomes strongly basophilic, indicating considerable protein synthesis. Small spherical vacuoles, possibly containing fatty yolk, appear and increase numerically as the primary oocyte enlarges (Figure 3I). This condition corresponds to the oil drop stage *Haliotis discus hannai* (Tomita, 1967). In our histological sections, the germinal epithelium, oogonia, and primary oocytes are covered by a thin membrane which may be a fixation artifact. It may be seen sloughed away from their surface (Figure 3I).

During leptotene of phosphase I, chromosomes appear as fuzzy threads that are distributed uniformly along the periphery of the nucleus. The nucleolus is small, indistinct, and ovoid, and lies appressed to the nuclear membrane. In zygotene and pachytene, the chromosomes shorten into heavier strands that radiate as a bouquet from one side of the nucleus (Figure 5A). The nucleolus becomes spheroid. A synizetic knot may form when a dense aggregate of chromosomes attaches to the nucleolus. These conditions are similar to the generative phase of the nucleus as given by Raven (1966). He states further that this phase is typical of mollusean oogenesis. Initially the chromatin is extremely basophilic. As the nucleus enlarges it loses its basophilia. The chromatin becomes dispersed and displaced toward the animal pole opposite the cytoplasmic stalk (Figure 3H). Individual chromosomes become invisible. The conditions are characteristic of the vegetative phase of Raven (1966) and may be homologous to the diffuse stage of the first prophase. The functional significance of the diffuse stage is unknown (Brown and Bertke, 1969), but the vegetative phase is prominent during the greater part of the growth period of the primary oocytes, so it may be important in growth and vitellogenesis (Raven, 1966). The nucleolus, upon reaching a diameter of about 3 μ, enlarges rapidly, increases in basophilia, and becomes more distinct. Buds and vacuoles appear in the nucleolus (Figure 5B) indicating production of ribosomal RNA (Brown and Bertke, 1969).

A system of organelles that may be a Golgi apparatus first appears in the primary oocytes as a flattened basophilic patch on the vegetal side of the nucleus. During growth of the oocyte, it gradually thickens and resolves into basophilic linear strands that run parallel to the polar axis of the oocyte. The side adjacent to the nucleus develops one or more large basophilic lobes (Figure 5C). When the primary oocyte reaches its maximum volume and as it moves toward the digestive gland, the lobes flatten, and the organelle spreads thinly around the vegetal half of the nucleus (Figure 5D). The apparent Golgi apparatus is invisible in detached primary oocytes. Though we did not employ standard methods for detecting the Golgi apparatus, the general appearances and behavior of the organelles resemble the generalized cycle of the Golgi apparatus described by Raven (1966) for many molluscs. In molluscs, vitellogenesis is often associated with the Golgi apparatus

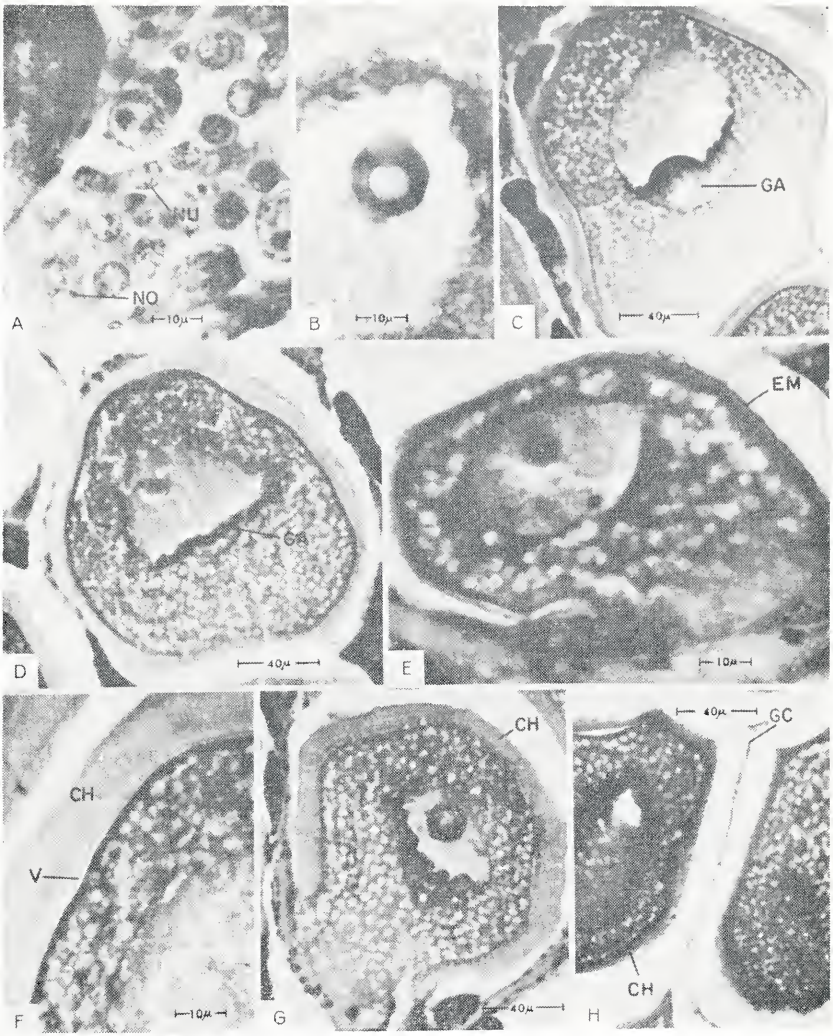

FIGURE 5—A—Generative phase of primary oocyte showing association of chromosomes with the nuclear wall. NU = nucleus, NO = nucleolus. B—Budding and vacuolated nucleolus in primary oocyte. C—Lobed condition of apparent Golgi apparatus in primary oocyte. GA = apparent Golgi apparatus. D—Flattened condition of apparent Golgi apparatus (antecedent of lobed condition) in primary oocyte. GA = apparent Golgi apparatus. E—Young primary oocyte partly enveloped by thin eosinophilic membrane. Membrane is discontinuous around side of cell adjacent to trabecula. Arrows indicate ends of membrane. EM = eosinophilic membrane. F—Chorionic and vitelline membranes of primary oocyte. CH = chorion, V = vitelline membrane. G—Chorion that is discontinuous on side of oocyte adjacent to trabecula. CH = chorion. H—Edge of gelatinous coating surrounding chorion of primary oocyte. GC = gelatinous coating. CH = chorion.

which concentrates substances used in the formation of either proteid or fatty yolk, or both (Worley, 1944). Yolk is suspected or known to arise from the Golgi apparatus in the opisthobranch gastropods,

Aplysia (Bolognari, 1960a, b), and *Navanax* (Worley and Worley, 1943); the pulmonate gastropods, *Ercmina* (Fahmy, 1949) and *Limnaea* (Bretschneider and Raven, 1957); the amphineurans, *Mopalia* and *Chaetopleura* (Anderson, 1965); and the pelecypod, *Mytilus* (Worley, 1944). Since the apparent Golgi apparatus is such a prominent feature during yolk formation in the young primary oocyte of red abalone, it may be responsible for the accumulation of yolk.

During growth of the primary oocyte, a thin eosinophilic membrane appears and thickens uniformly around the plasma membrane, except at the point of attachment of the oocyte to the follicular wall (Figure 5E). Whether this membrane is either an incipient vitelline membrane or a chorion is not clear, but two eosinophilic layers soon become evident. We call the inner layer the vitelline membrane, and the outer layer the chorion (Figures 5F and 5G). According to Raven (1966), the molluscan chorion is formed by an envelope of follicle cells. The red abalone lacks follicle cells; thus what we term the chorion is produced differently. The vitelline membrane rapidly reaches a maximum thickness of about 1 μ. A thick gelatinous coating surrounds the chorion of a fully grown oocyte prior to spawning (Figure 5H).

Necrosis of vegetative oocytes was observed in each monthly sample. The first visible signs of necrosis occur in the nucleus. The chromatin becomes strongly eosinophilic, less granular, and distributed uniformly (Figure 6A). The nuclear membrane convolutes and breaks down; the

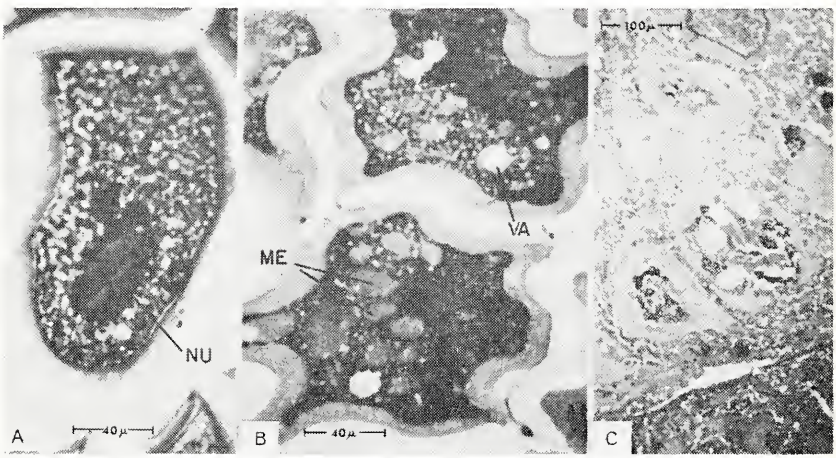

FIGURE 6—A—Darkly stained nucleus of primary oocyte, representing first visible stage of necrosis. NU = nucleus. B—Necrotic primary oocyte. Notice large vacuolations and eosinophilic masses. VA = vacuolation, ME = eosinophilic masses. C—Late necrosis showing complete breakdown of primary oocytes.

nucleus shrinks and gradually disappears. The numerous small vacuoles present in the cytoplasm enlarge and may fuse. Eosinophilic inclusions unite and form large textureless bodies up to 40 μ in diameter (Figure 6B). Simultaneously basophilic inclusions become more evident, probably due to the unmasking effected by aggregations of the eosinophilic inclusions. Subsequently, the cell surface becomes highly irregular, the

vitelline membrane disappears, the chorion ruptures and the cellular content disperses into the lumen (Figure 6C). During late necrosis, amoebocytes like those present in the blood sinuses occur in the ovarian lumen among the remnants of oocytes. Amoebocytes are released possibly by the breakdown of trabeculae and may be phagocytes. Resorption of vegetative oocytes probably occurs. In fresh ovaries, highly necrotic areas occur as small patches of varying sizes and shapes. The patches are characteristically flaccid while non-necrotic areas are firm. Massive proliferation of oogonia was observed commonly in the distal portions of trabeculae in advanced stages of necrosis.

The ovaries were never devoid of full grown oocytes that would typify a spawned condition. Thus, the histological evidence also indicates that the red abalone may be a potential spawner throughout the year in the Fort Bragg area.

Induction of Spawning

Shock caused by changes in temperature is a primary inducer of spawning in many marine invertebrates (Giese, 1959). Ino (1953) promoted spawning in *H. discus* and *H. sieboldii* by adding warmed sea water to aquaria containing mature specimens. He also noted that some specimens kept in warm water for several hours spawned after being returned to natural sea water. Carlisle (1945, 1962) found that red abalone spawned after a period of desiccation, however, this would not occur naturally in sublittoral populations. Cox (1962) believes that warm water induces spawning in the red abalone. Rapid changes in temperature caused by internal waves often occur in localized areas. At La Jolla, California, Fager (1968) found that temperature shifts of 5 C or more could occur in minutes. Extensive isotherms and internal waves having a periodicity of about 17 min and a temperature change of 1 C or more are known to occur along the northern California coast (James A. Gast, Dept. of Oceanography, Humboldt State College, pers. comm.). Internal waves can be propagated at the horizontal interfaces of the isotherms. These sudden temperature changes that occur frequently may cause year-round spawning of individual red abalone by inducing the release of gametes in small amounts. An alternative explanation is that a given individual may have an annual reproductive cycle with one spawning, but that as a population, the cycles are not in phase. This explanation does not appear plausible since histological evidence indicates that throughout the year mature gametes were present in all specimens collected.

SUMMARY

1. Ten subtidal red abalone specimens were collected monthly near Fort Bragg, California, to study the reproductive cycle, gonadal histology, and gametogenesis.

2. The hypothesis that the sex ratio was 1:1 was tested and accepted.

3. The gonad index (Boolootian et al. 1962) and gonad bulk index (Newman, 1967) were calculated for each specimen. No significant rank correlation existed between the two indices because the total areas of the sections are highly variable for a given shell length.

4. The hypothesis that the variation of gonadal indices differ insignificantly from month to month was tested using the analysis of variance. The hypothesis was accepted.

5. The general histology of the gonad is described and agrees with the description given by Crofts (1929) for *H. tuberculata* and by Newman (1967) for *H. midae.*

6. Gametogenesis is described, particularly oogenesis. Proliferation of oogonia occurred in specimens collected throughout the year. Growth of the primary oocyte is characterized by the presence of a large apparent Golgi apparatus which disappears upon maturation of the oocyte. Necrosis of mature oocytes was observed, and we found that areas of the ovary in which advanced stages of necrosis were occurring were characterized superficially by the loss of turgidity.

7. Possible spawning mechanisms are discussed.

8. Our study indicates that lack of seasonal variation of gonadal indices is related to the fact that gonads contain apparently mature gametes throughout the year. Furthermore, the gonad index cannot be used to determine time of spawning of a population of red abalone.

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NOTES

WHITE-TAILED KITES NESTING IN DEL NORTE COUNTY, CALIFORNIA

There is no record in the literature of white-tailed kites (*Elanus leucurus*) nesting in Del Norte County or any farther north than Humboldt Bay, California.

On June 9, 1969, a pair of white-tailed kites was observed hunting the east side of Lake Earl, Del Norte County. On July 16, 1969 the kites were missing. Upon investigation it was learned that the kites had been shot off their nest illegally by a collector for the purpose of mounting. The nest was located on the east side of Lake Earl, approximately 200 yards north of the mouth of Jordan Creek, in a wood lot of second growth Douglas fir (*Pseudotsuga Menziesii*), redwood (*Sequoia sempervirens*) and Monterey cypress (*Cupressus macrocarpa*).

The timber land is interspersed with pasture which is utilized by cattle.

—*Merlin Hehnke, California Department Fish and Game, Eureka, California.* *Accepted for publication April 1970.*

THE SAGEBRUSH LIZARD—A NEW LOCALITY AND COMMENTS ON ITS DISTRIBUTION IN WEST CENTRAL CALIFORNIA

In west central California, populations of the sagebrush lizard (*Sceloporus graciosus*) occur at elevations at or above 3,200 ft and are disjunct, Stebbins (1954). Isolated populations occur at the following localities with the lowest elevation of occurrence indicated: Mount Diablo, 3,200 ft Contra Costa County; Santa Rita Peak, 4,500 ft, San Carlo Peak, 4,600 ft and San Benito Mountain, 4,500 ft San Benito County; Loma Prieta, 3,500 ft and Summit Chuai, 3,592 ft Santa Cruz County. The species is also thought to occur on Mount Hamilton, Santa Clara County.

It stands as evidence for the disjunct nature of the sagebrush lizard populations that Banta and Morafka (1968) did not collect specimens in what appeared to be suitable habitat in the Pinnacles National Monument and Bear Valley, San Benito and Monterey counties.

On 11 July 1969, about 12 miles south of Carmel, two adult males of the sagebrush lizard were collected $\frac{1}{4}$ mile southwest of Twin Peaks at 3,200 ft elevation in the Santa Lucia Range, Monterey County, California. Twin Peaks is $4\frac{1}{2}$ air miles inland from the coastline at Rocky Point. Data on these specimens are as follows: sv = 55.2, 50.5 mm, tail length = 83.3, 75.0 mm, dorsal scale count, i.e., number of scales between the posterior margin of the interparietal and a line connecting the posterior surfaces of the thighs = 62, 59.

Both specimens were collected on the shoulder of a dirt road which traversed the ridge top in chaparral habitat. Spanish bayonet, *Yucca,* and clumps of oak and Spanish broom, *Spartium,* were scattered among chamise, *Adenostema.* The substrate was decomposed granite. To my knowledge these specimens are the first from Monterey County.

The nearest population is 50 miles east in the Diablo Range at Santa Rita Peak, San Benito County. Since the extensive lowlands of the Salinas River drainage stretch between the Diablo and Santa Lucia ranges, it is probable that these populations are disjunct.

On the basis of this new locality, it is suspected that the sagebrush lizard occurs, probably in disjunct populations at high elevations, throughout the Santa Lucia Range. If it does, the species exists in mountain areas completely encircling the Sacramento and San Joaquin valleys. A search should be made throughout the Santa Lucias.

I want to thank Dr. R. C. Stebbins for advice in the preparation of this paper and James F. Lynch who introduced me to this lizard.

—*Thomas G. Balgooyen, Museum of Vertebrate Zoology, University of California at Berkeley, California 94720.* *Accepted March 1970.*

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INTRODUCTION OF BLUE CATFISH INTO CALIFORNIA

On October 23, 1969, 1,990 blue catfish, *Ictalurus furcatus* (LeSueur), were flown from Stuttgart, Arkansas, to Gillespie Airport for introduction into Lake Jennings, San Diego County. Dr. Fred P. Meyers, Bureau of Sport Fisheries and Wildlife, Fish Farming Experimental Station, Stuttgart, Arkansas, coordinated procurement of the fish. Only one catfish was lost during shipment.

Blue catfish are known to feed on the freshwater Asiatic clam, *Corbicula fluminea. C. fluminea* is abundant and a nuisance in many southern California waters but is virtually unutilized by present game fish populations. Although the blue catfish probably will not afford any biological control over the clams, it is likely they will convert appreciable quantities of this forage animal to fish flesh for angler use. The blue catfish also attains the largest size of any of the American catfishes, and would enhance our fisheries by providing another trophy sized fish. Consequently, following a recommendation by Alex Calhoun, Chief, Inland Fisheries Branch, we introduced the blue catfish on an experimental basis.

One thousand seven hundred and fifty-eight of the catfish were marked with a right pelvic clip and released into Lake Jennings on October 23, 1969. The remaining blue catfish were transported by hatchery planting truck to the Department's Chino Fish and Wildlife Base to be used for future broodstock. Average length of the imported

fish was 6.46 inches TL with a range of 3.39 to 8.46 inches. Their average weight was 1.08 oz. Prior to liberation into Lake Jennings, 211 of the catfish were held in a live car for a period of 21 hours. No mortality occurred.

On November 18, 1969, 2,014 channel catfish, *Ictalurus punctatus*, averaging 6.65 inches were marked with a left pelvic clip and released into Lake Jennings for comparison of growth and harvest rates with the blue catfish.

—*William M. Richardson, James A. St. Amant, Lawrence J. Bottroff, and Wayne L. Parker, Inland Fisheries Branch, Region 5, California Department of Fish and Game. Accepted April 1970.*

OCCURRENCE ON THE HIGH SEAS OF A STEELHEAD TROUT IN ITS NINTH YEAR

A steelhead trout (*Salmo gairdneri*) of unusual age was captured in the eastern North Pacific Ocean on September 11, 1969, by the RV *George B. Kelez,* Bureau of Commercial Fisheries. It was taken in a surface gillnet at lat 53°00′ N, long 160°00′ W (about 100 miles south of the Shumigan Islands, Alaska) during a survey to determine the relative abundance and distribution of Pacific salmon (*Oncorhynchus* spp.). The fish, a female, was 33.7 inches (857mm) long, was emaciated, and was recovering from its last spawning migration (one of four in as many years). About 12 eggs that had been retained in the ovaries after the last spawning were being resorbed, and the next generation of immature eggs was present.

Age determination was made from microprojections of scale impressions on a plastic card (Koo, 1962; Mosher, 1950). The scales showed a freshwater age of 3 years and an ocean age of 2 years before the first of four successive spawnings, plus additional summer growth in 1969 (3.1GGGG+). Thus the fish had completed 8 years and was in its ninth year (Figure 1).

Plastic impressions of scales were sent to several agencies for verification of the age of this fish. All experts agreed on the life history of the specimen (i.e., 3 years in fresh water, 2 years in the ocean, four successive annual spawning migrations, and a period of post-spawning recovery in the summer of 1969). Agreement was not complete, however, on the total age of the fish (8 or 9 years) because of a difference in the interpretation of steelhead age designations by the Koo (1962) formula and by F. H. Sumner (pers. comm., Dec. 18, 1969). According to Mosher (pers. comm.) the use of Sumner's interpretation increases total age of the fish by 1 year—the year that is added between the first year of ocean growth and the initial spawning check.

Most of the literature reviewed showed 7 years to be the maximum age attained by steelhead trout (Snyder, 1925, 1933; Neave, 1940; Pautzke and Meigs, 1941; Meigs and Pautzke, 1941; Shapovalov and Taft, 1954; Maher and Larkin, 1955; Bali, 1959; Withler, 1966; Bulkley, 1967; Narver, 1969). Sumner (1948), however, reported an 8- and a 9-year-old steelhead trout.

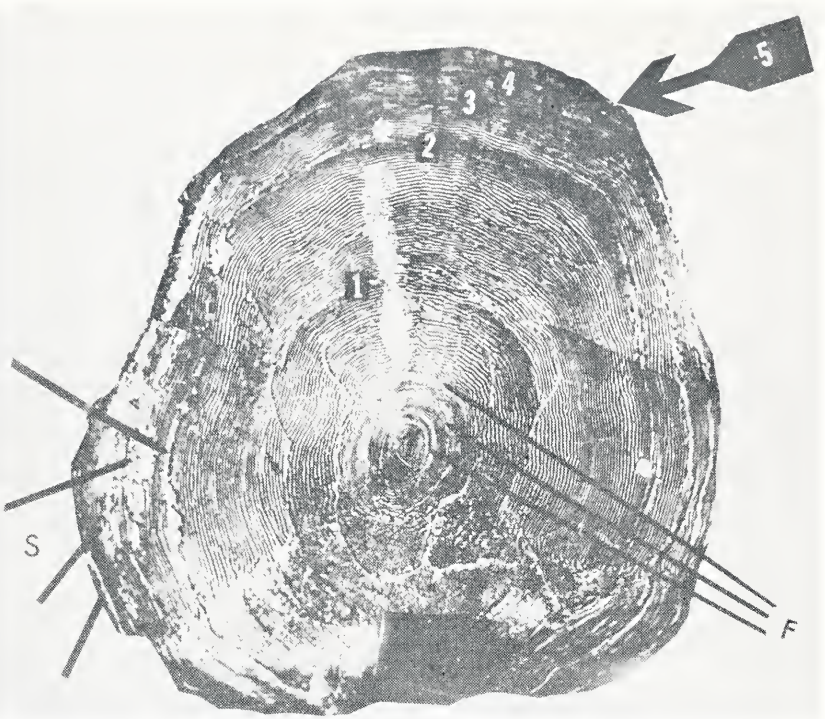

FIGURE 1—Scale of steelhead trout (*Salmo gairdnerii*) in its ninth year, showing three freshwater marks ("F"), four spawning checks ("S"), and five ocean winter marks (numbers 1–5). *Microphotograph by Kenneth H. Mosher.*

Because we had captured this fish on the high seas in September and because it had new eggs developing, the fish probably would have survived to another spawning and year of life, thereby putting it in its 10th year. The only other 8-year-old steelhead trout was recorded at least 25 years ago (Sumner, 1948); Sumner aged both his 1945 fish and the 1969 steelhead as 9-year-olds (Sumner, pers. comm.). As sport and commercial exploitation of steelhead trout stocks has increased since 1945, the average age of fish in the population would probably decrease (Watt, 1968), as would the probability of a fish reaching an advanced age. Thus, the fact that a steelhead trout in its ninth year (or 8-year-old, depending on the total age designation used) was very unusual in 1945, would in theory make such an occurrence even more remarkable today.

ACKNOWLEDGMENTS

I thank the following persons for their interpretations of the age of the fish: T. S. Y. Koo, University of Maryland; Kenneth Mosher, Bureau of Commercial Fisheries, Seattle; G. Lewis Robins, Fisheries Research Board of Canada, Nanaimo; Leo Shapovalov, California Department of Fish and Game; and Francis H. Sumner, Oregon State Game Commission.

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—*Percy M. Washington, Bureau of Commercial Fisheries, Seattle, Wash. Accepted for publication June 1970.*

OCCURRENCE OF KING (CHINOOK) SALMON IN THE KINGS RIVER, FRESNO COUNTY

On April 3, 1970, three small (10.5–11.0 cm, TL) king salmon, *Oncorhynchus tshawytscha*, were taken from Mill Creek, about 150 m above its confluence with the Kings River, by myself and students of my Ichthyology class. The mouth of Mill Creek is about 2 km below Pine Flat Dam. The presence of salmon in the Kings River drainage has not been reported since the fall of 1942 when Chester Woodhull and William A. Dill, biologists with the Department of Fish and Game, collected small king salmon in the same general area from which the present fish were taken (unpublished report, 1942).

The king salmon has probably not been a regular member of the fish fauna of the Kings River for many decades, if ever. The river drains into Tulare Lake which is connected to the San Joaquin River, by Fresno Slough, only during years of high water. Thus, any salmon in

the Kings River would most likely be strays from the yearly run up the San Joaquin River. Nevertheless, the 1942 report by Woodhull and Dill indicates that previous to 1927, when a direct connection to the San Joaquin River, the Kings River by-pass, was constructed, salmon occasionally went up the Kings River during the high water years. It would seem likely that this occurred more often before irrigation diversions reduced flows in the lower part of the Kings River. After 1927, salmon runs occurred with greater frequency, especially noticeable runs occurring in 1927, 1938 and 1940. No runs have been noticed in recent years, presumably because the construction of Friant Dam has resulted in decreased flows into the San Joaquin River since 1946, thus virtually eliminating the San Joaquin run that was the source of the Kings River salmon. However, the winter of 1968–69 was one of exceptionally high precipitation and run off, and the high water allowed a few king salmon to reach the upper San Joaquin region. On July 1, 1969, a 30 inch male king salmon was caught by an angler below Friant Dam (D. Christenson, pers. comm.).

Apparently a few king salmon also made it up the Kings River, where they spawned. It is possible that salmon were present in the Kings River in other years after 1942 as well, but they went by unnoticed simply because no one had looked for them.

The three present salmon were taken from a large pool in Mill Creek which had a temperature of 21 C. The temperature of the Kings River was 13 C. Aside from this temperature difference, there was nothing to prevent the salmon from entering the Kings River. Other fish collected from the Creek, in approximate order of abundance, were: Sacramento squawfish (*Ptychocheilus grandis*), California roach (*Hesperoleucus symmetricus*), green sunfish (*Lepomis cyanellus*), Sacramento sucker (*Catostomus occidentalis*), carp (*Cyprinus carpio*), rainbow trout (*Salmo gairdnerii*), smallmouth bass (*Micropterus dolomieu*), white catfish (*Ictalurus catus*), largemouth bass (*M. salmoides*), golden shiner (*Notemigonus crysoleucas*), and bluegill (*Lepomis macrochirus*).—*Peter B. Moyle, Department of Biology, Fresno State College, Fresno, California 93710. Accepted June 1970.*

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Notice is hereby given that the Fish and Game Commission shall meet on October 2, 1970, at 9:00 a.m. in the Main Auditorium, Resources Building, 1416 Ninth Street, Sacramento, California, to receive recommendations from its own officers and employees, from the Department and other public agencies, from organizations of private citizens, and from any interested groups as to what, if any, regulations should be made relating to fish, amphibia, and reptiles, or any species or subspecies thereof.

Notice is hereby given that the Fish and Game Commission shall meet at 9:00 a.m. on October 30, 1970, in the Supervisors' Chambers, County Courthouse, Redding, California, for public discussion of and presentation of objections to, the proposals presented to the Commission on October 2, 1970, and after considering such discussion and objections, the Commission, at this meeting, shall announce the regulations which it proposes to make relating to fish, amphibia and reptiles.

Notice is hereby given that the Fish and Game Commission shall meet on December 4, 1970, at 9:00 a.m. in Room 1138, New State Building, 107 S. Broadway, Los Angeles, California, to hear and consider any objections to its determinations or proposed orders in relation to fish, amphibia and reptiles or any species or subspecies thereof for the 1971 sport fishing season, such determinations and orders resulting from the hearing held on October 2, 1970 and October 30, 1970.

FISH AND GAME COMMISSION
Leslie F. Edgerton
Executive Secretary

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